THE ELEMENTARY PRINCIPLES OF WIRELESS TELEGRAPHY

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OF

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BY

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PART II

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PREFACE TO FIRST EDITION

In presenting this Handbook, the author has endeavoured to explain, in the simplest possible manner, the theory and practice of Wireless Telegraphy.

It has been his aim to make the subject intelligible to persons who do not possess much technical knowledge, and to be at the same time brief and accurate.

The book has been so arranged as to be useful as a reference book on the subject for students and amateurs in this special branch of electrical science.

Further and more complete explanations of the various phenomena described can be obtained from the standard scientific works on the subject, but it has been the object of the author to deal with the subject clearly and simply without going too deeply into the many highly technical problems involved.

R. D. B.

PREFACE TO SECOND EDITION

WITH the object of increasing the usefulness of this Handbook, the author has extended its scope without going any more deeply into the technical side of the subject.

Since the book has been used largely in the training of Telegraphists who are frequently called upon to take sole charge of complete Wireless Telegraph Installations, the author has endeavoured to cover all parts of the transmitting and receiving apparatus in such a way as to give the student a sound working knowledge of the apparatus entrusted to his care.

For the convenience of the student, the new edition is divided into two parts. Part I. contains, in addition to the matter published in the first edition, and now revised, a good deal of further information regarding Receivers and Aerials. In Part II. the component parts of a Transmitter are explained separately, and the theory of the condition of resonance under which they can most effectively be combined, and to which each part should be adjusted to form an efficient transmitter, is fully discussed.

R. D. B.

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ELEMENTARY PRINCIPLES OF WIRELESS TELEGRAPHY

CURVE DIAGRAMS

In previous chapters we have used simple curve diagrams to illustrate various results, and their meaning has been sufficiently obvious to permit our doing so without fuller explanation.

The explanations of the various phenomena we shall describe in the second part of this book, however, are greatly facilitated by a more extensive use of such diagrams. We think, therefore, that no apology is necessary for printing a few brief notes on the meaning of curve diagrams for the guidance of those students who are not acquainted with their use.

801. The first principle underlying all curve diagrams is the representation of relative values by distances drawn to a predetermined scale. Thus, if we determine beforehand that a definite distance shall represent a unit value of the particular factor we wish to consider, we can represent any value of that factor by a distance corresponding in scale to the value we wish to define.

802. For example, let us suppose that we decide on a scale of 1 inch = 1 lb., then it is evident that we can

represent a weight of 4 lbs. by a distance of 4 inches, or a weight of 7 lbs. by a distance of 7 inches.

Similarly, if we decide on a scale of 1 inch = 1 minute, we can represent a length of time of 5 minutes by a distance of 5 inches, or a length of time of 30 seconds by a distance of half an inch.

803. A curve diagram is a graphical illustration based on this principle, of the **relationship** of any two factors when the value of one is dependent upon the value of the other.

804. For convenience curves are usually plotted on "sectional" paper or "squared" paper, *i.e.* paper divided into squares of equal dimensions of anything from half an inch to one-twentieth of an inch each way.

A table giving the values of one factor and showing the corresponding values of the other factor is useful for some purposes, but without considerable calculation it is impossible to obtain from such a table an idea of the general relation which the two factors bear to one another. A curve diagram of the relationship of the two factors, however, will show us at a glance not only all the corresponding values of the two factors, but also their general relation to one another.

805. Let us take an example and suppose that an empty bucket is placed under a running tap. Now the weight of the bucket will increase (until it is full) so long as the water is flowing into it, so that in this case we have two varying factors which bear a certain relation to one another, namely, the **weight** of the bucket and the **length of time** that the water is flowing into it.

806. If we take the weight of the bucket at various intervals of time, we can tabulate our results in two columns, one column giving the length of time during

which the water has been running into the bucket, and the other column giving the corresponding weight of the bucket. Let us suppose that during five minutes the following readings are taken :

TABLE A

Length of Time.	Weight of Bucket.
Mins.	Lbs.
0	1
$\frac{1}{2}$	2
$1\frac{3}{4}$	$4\frac{1}{2}$
3	7
$3\frac{1}{2}$	8
5	11

807. The first reading in the table was taken before any water had flowed into the bucket, and therefore gives the weight of the bucket by itself. Now from a study of this table of readings, it would be difficult, without making some calculations, to tell at what rate the water was pouring into the bucket or whether it was flowing in at the same rate all the time. Moreover, the table only gives us the weight of the bucket at definite moments, and if we wished to know how much the bucket weighed at intermediate moments, we should have to calculate it. If, however, we make a curve diagram to illustrate the results obtained, we can get all this information at a glance.

THE STRAIGHT LINE

808. In Fig. 151 the results given in the table are "plotted" as points on sectional paper, the distances along the horizontal axis, or, as they are usually called,

the "**Abscissae,**" representing the length of time during which the water has been flowing into the bucket, and the distances along the vertical axis, or "**ordinates,**" representing the weight of the bucket. If a line be drawn, as shown, connecting all these points together, it will be noticed that this forms a *straight* line.

809. Now from the "curve" we can tell at a glance

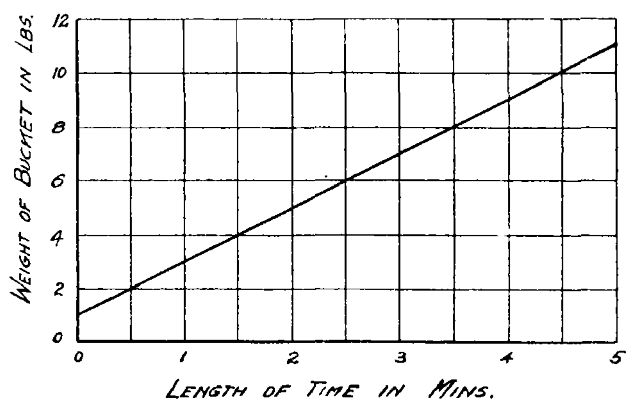


FIG. 151.

the weight of the bucket at any moment during the time it is under the tap by measuring the height of the ordinate at that moment, and also at what moment its weight has risen to any particular value by measuring the length of the abscissa at that particular weight: thus from the curve we can see that at the end of $2\frac{1}{2}$ minutes the weight of the bucket was 6 lbs.

810. **When the magnitude of one factor is directly proportional to the magnitude of another factor,** that is to say, **when the rate of change of one factor with respect to the other is uniform, the curve diagram representing their relationship will take the form of a straight line.**

Thus, from a glance at the curve illustrating the results of the case in point, we can tell that the weight of the bucket is directly proportional to the length of time that the water is running into it ; or in other words, its weight is increasing at a uniform rate throughout that time.

811. It must be clearly understood that although any **point** on the curve represents the weight of the bucket at that moment, the "**curve**" itself represents the **relationship** of the weight and the time, that is to say, the curve represents the change in the weight of the bucket.

In this particular case the curve is sloping upwards, thus denoting an increase in weight ; but if the curve, instead of starting at a minimum value and sloping upwards, starts at a maximum and slopes downwards, it would clearly represent a **decrease** in the weight of the bucket, as the time elapsed increases, which would occur, for instance, if the water was flowing out of the bucket instead of into it.

812. We may say then that **the direction of the slope of a curve indicates whether the factor represented by the ordinates is increasing or decreasing.**

Steepness of Slope of a Curve

813. If we plot several "curves" on one sheet of paper representing the relation between two factors, under conditions such that the rate of change is different in each case, we shall get curves of different slope.

For example, let us suppose that the experiment described in paragraph 805 is repeated with the tap turned on fuller in one case and less in another.

814. In that experiment the weight of the bucket

increased by 10 lbs., *i.e.* from 1 lb. to 11 lbs., in five minutes. Since 1 gallon of water weighs 10 lbs., it is evident that during that experiment the water was flowing into the bucket at the uniform rate of 12 gallons per hour.

If then we adjust the tap, so that the water flows at the rate of 6 gallons per hour, and starting with the empty bucket again take readings at intervals during five minutes, the weight of the bucket at different moments will be as shown in Table B.

TABLE B

Length of Time.	Weight of Bucket.
Mins.	Lbs.
0	1
1	2
2	3
4	5
5	6

815. Similarly, if the tap be adjusted so that the water flows at the rate of 18 gallons per hour, the weight of the bucket will be as shown in Table C.

TABLE C

Length of Time.	Weight of Bucket.
Mins.	Lbs.
0	1
2	7
3	10
4	13
5	16

816. In Fig. 152 these three sets of readings are plotted as three separate "curves" A, B, and C, from which it will be seen that each of them takes a different slope, the one with the steepest slope, "C," representing the greatest **rate of change** in the weight of the bucket, and the one with the least slope, "B," repre-

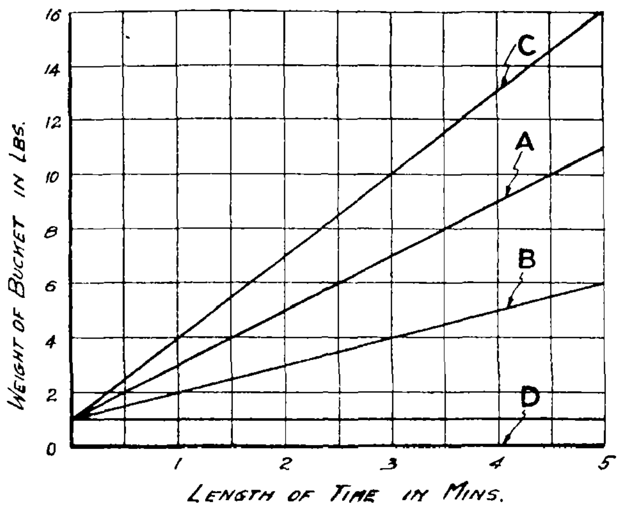


FIG. 152.

senting the smallest **rate of change** in the weight of the bucket.

817. If the tap were turned off altogether, then it is evident that there would be no change in the weight of the bucket and that it would remain at 1 lb. throughout the five minutes. In this case the "curve" representing the relation between weight and time would be as shown by "D" in Fig. 152, that is a line parallel with the axis of time.

818. We may say then that (1) when the curve lies *parallel with one of the axes, it indicates that there* is no change in the magnitude of one factor with respect to a change in the other factor, and (2) that **the steepness of a curve represents the rate of change in one factor with respect to a change in the other factor.**

819. Since the steepness of a curve represents the rate of change in one factor with respect to the other,

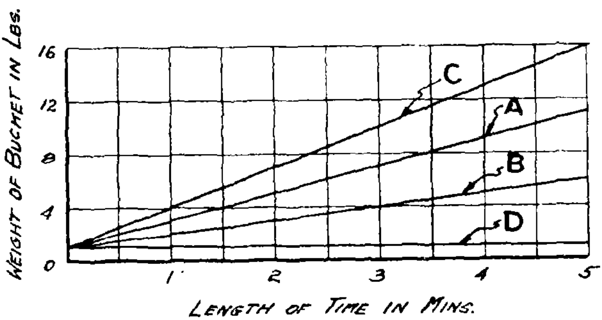


FIG. 153.

it is evident that when two or more curves are plotted representing the functions of two factors under different conditions (as, for instance, those illustrated in Fig. 152), the relative effect of these different conditions can be seen at a glance by the difference in the steepness of the "curves."

820. The student, however, must be cautioned against comparing the slopes of curves plotted to different scales, because the slope of any particular "curve" will depend upon the scales chosen when plotting it.

Thus Fig. 153 shows exactly the same results

illustrated in Fig. 152, but in Fig. 153 the weight is plotted to a different scale.

So far we have only taken cases where the change in one factor with regard to another is uniform, and the curve, as we have shown, then takes the form of a straight line.

821. It is evident that when one factor is not directly proportional to another factor, that is to say, when the change in one factor is not uniform, the curve diagram representing their function will take the form of a line **varying in steepness,** because the steepness, as we have shown, represents the rate of change. The exact shape of this line will depend upon the law governing the relation between the two factors, but the purpose of these notes will be served by taking typical examples of two or three different laws which are most likely to be met with in the study of Wireless Telegraphy.

THE LOGARITHMIC CURVE

822. Let us take the case of water flowing from a full tank into an empty tank through a connecting pipe, as shown in Fig. 154. If we neglect the effect of the inertia of the water, the rate at which the water will flow from one tank to the other depends upon two things: (1) **the pressure,** which is determined by the difference in the height of the water in the two tanks, and (2) **the friction** in the

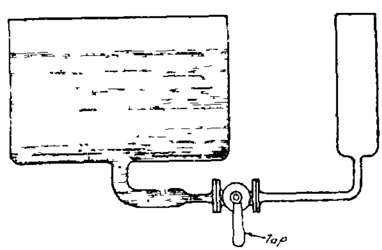


FIG. 154.

connecting pipe. Of these factors, for the purpose of this explanation, the latter can be taken as remaining constant, so that in this case we may say that the flow of water depends only upon the **difference** in the water level in the two tanks. If the size of the full tank is very large compared with that of the empty tank, then we can assume for the sake of simplicity that the water level in the large tank remains unaltered as the small tank fills. Now, if the *difference in level* remained the same, the water would flow at a uniform rate and the curve representing the relationship of time and flow would take the form of a straight line parallel with the axis of time. But any flow in the water through the pipe causes an increase in the water level of the small tank, with the result that the pressure, causing the water to flow, decreases so long as any water is flowing.

823. Now we will assume for the purpose of this argument that **the flow of water is proportional to the pressure**; so that if the pressure decreased at a uniform rate, the flow of water would also decrease at a uniform rate, and the curve representing the function of the flow of water and time would take the form of a straight line starting at a maximum and sloping downwards until it reached zero.

A little consideration, however, will show us that the pressure will not decrease at a **uniform** rate, because the decrease in the pressure is due to the flow of water into the small tank, and therefore the rate at which the pressure decreases depends upon the rate at which the water runs, *i.e.* depends upon the flow of water.

824. It follows, therefore, that since a decrease in the pressure causes a decrease in the flow of water, this in turn causes a decrease in rate at which the pressure

falls, and therefore also in the rate at which the flow of water decreases.

The result is that the flow of water will start at a maximum when the tap connecting the two tanks is first turned on, and that it will decrease rapidly at first and then more and more slowly as the water level in the small tank approaches that of the large tank, with the result that, although the flow of water gradually decreases, its rate of decrease gets less and less and it would take an infinite length of time before it actually ceased to flow.

825. We have shown that a curve sloping downwards represents a decrease in one factor with respect to another, and further that the steepness of the slope represents the rate of decrease. It is evident, therefore, that the curve representing the flow of water under these conditions will slope downwards, commencing with a maximum steepness and continuing with a gradually decreasing slope until it nearly, but never quite, reaches a certain minimum value, which in this particular instance is zero.

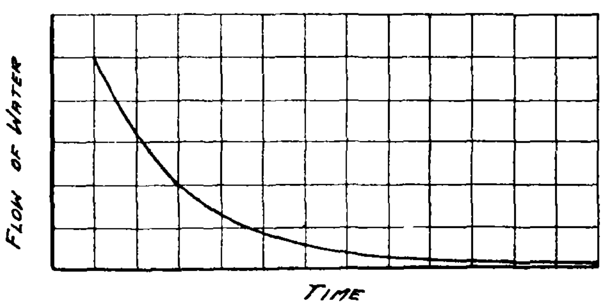


FIG. 155.

An illustration of this curve is shown in Fig. 155, in which the ordinates represent the flow of water and the

abscissae represent time. It is known as a "logarithmic" curve, and is frequently met with in the study of "Wireless" and other electrical phenomena. For instance, if an E.M.F. be applied to a condenser, and the current flowing into the condenser through a resistance be plotted against time, the curve will take this form.

826. A "logarithmic" curve can also take the form shown in Fig. 156, where one of the factors being

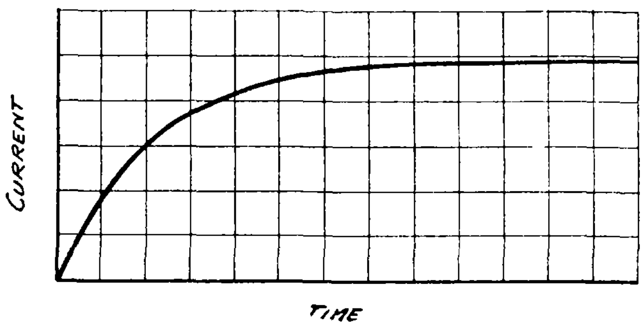


FIG. 156.

plotted starts at a minimum value and increases rapidly at first, and then more and more slowly, always approaching, but never reaching, a definite maximum limit.

An example of this is the curve representing the flow of current through an inductance coil having resistance, when an E.M.F. is applied across it, and another example is the curve representing the velocity of a body falling through the air.

The Parabola

827. **When one factor is proportional to the square of another factor, the curve representing their relationship will take the form shown in Fig. 157.** This curve is known as a "**parabola.**" At first sight it may appear to be very similar to the "logarithmic" curve shown *in Fig. 156.* There is, however, a fundamental difference between

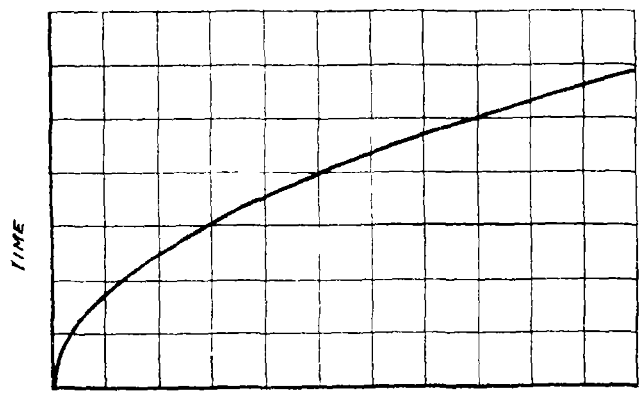


FIG. 157.

the two, for while in the "logarithmic" curve one factor always approaches a steady maximum or minimum value, in the "parabola" both factors continue to increase indefinitely.

An example of this is the curve illustrating the increase in the distance travelled by a body falling through space with elapse of time. When a body falls through the air, the friction with the air increases very rapidly with the speed, and for this reason the increase

in the speed of the body rapidly falls off, and it can never travel faster than a certain definite speed, depending upon its size and shape.

828. When a body falls through space (*i.e.* a vacuum), however, there is nothing to limit its speed, and this increases in proportion to the length of time it is falling. Now the distance fallen is proportional to its speed multiplied by the time it has been falling, and since, as we have seen, the speed is proportional to the time it has been falling, it follows that the distance fallen is proportional to the **square** of the length of time it has been falling.

829. Thus, if in one second it will have travelled a distance of 16 feet, in two seconds it will have travelled a distance of $2^2 \times 16$ feet $= 64$ feet, in three seconds $3^2 \times 16$ feet $= 144$ feet, and so on, the distance always increasing in proportion to the square of the length of time it has been falling.

If time be plotted along the vertical axis, and distance travelled along the horizontal axis, then the curve illustrating the velocity of a falling body will be as shown in Fig. 157. But if, as is usual, time be plotted along the horizontal axis, the curve will be as shown in Fig. 158.

830. Another example is the curve illustrating the watts absorbed in a given resistance for different values of current flowing through that resistance.

In Part I. we showed that Watts $= C \times V$, where C is the current in amperes, and V the volts required to overcome the resistance of the circuit through which that current is flowing.

831. From Ohm's Law we know that $V = CR$, where R is the resistance of the circuit. By substituting this value for V in the first-named equation, we get Watts $= C(C \times R) = C^2R$.

It follows, therefore, that **the number of watts absorbed in a given resistance is proportional to the square of the current flowing through that resistance.** The curve, shown in Fig. 158, therefore, will also represent

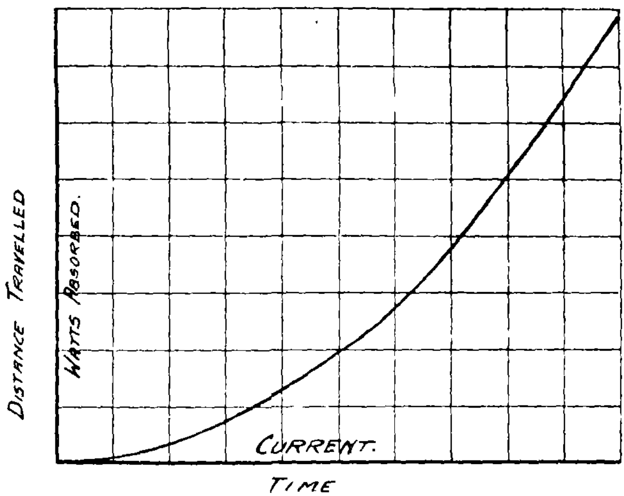


FIG. 158.

the increase in the watts absorbed in a given resistance as the current increases if current be plotted along the horizontal axis and watts absorbed by the resistance along the vertical axis.

THE HYPERBOLA

832. When one factor is inversely proportional to another factor, the curve representing their function will take the form shown in Fig. 159. This curve is known as a **Hyperbola.**

An example of this is the curve illustrating the

current flowing through a circuit of varying resistance when a constant voltage is applied to it.

833. In paragraph 78, Part I., we explained that the current flowing in a circuit is directly proportional to the voltage acting across the circuit, and inversely proportional to the resistance of that circuit. If, there-

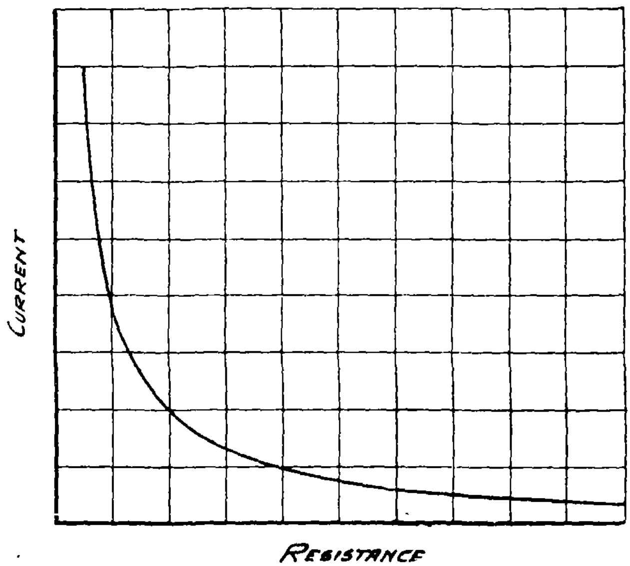


FIG. 159.

fore, the voltage remains constant, it follows that the current that will flow is inversely proportional to the resistance of the circuit.

834. Under these conditions it is evident that if the resistance be increased indefinitely, the current will fall off, and will get infinitely small when the resistance of the circuit is infinitely large.

When the value of anything is infinitely small it is said to be zero; so we may say that when, but not until, the resistance of the circuit is infinitely large, the current will fall to zero.

835. Similarly, if the resistance of the circuit be reduced indefinitely, the current will increase, and will be infinitely large when the resistance of the circuit is zero.

Positive and Negative Sense

836. In the examples we have taken up to the present, we have only considered the variation of factors in one direction, and although we have shown how the increase and decrease in one factor with relation to another can be represented by the rise and fall of a line plotted between the two axes of the curve, we have not yet shown how a change in the "sense" or direction of a factor can be illustrated.

837. In order to distinguish between the opposite directions of any factor, one is called the **Positive** sense, and the other the **Negative** sense. It makes no difference, as a rule, which is considered to be positive, but it is usual to consider the normal direction as the positive sense.

Thus, if we were considering the variation in the weight of a body, we should consider its weight to have a positive value when the effect of gravity tended to draw it towards the earth, and that it had a negative value when the effect of gravity tended to push it away from the earth. Thus the weight of a balloon would be considered as being +100 lbs. when deflated if it were then found to weigh 100 lbs., and as −500 lbs. when

inflated with hydrogen if it were then found that it required a force of 500 lbs. to keep it on the ground.

838. Similarly, if we were considering the strength of current flowing through a given circuit, or part of a circuit, and this current were sometimes in one direction and sometimes in the opposite direction, we should consider its value to be positive when flowing through the circuit past a predetermined point in one direction, and as being negative when flowing through the circuit past the same point in the opposite direction.

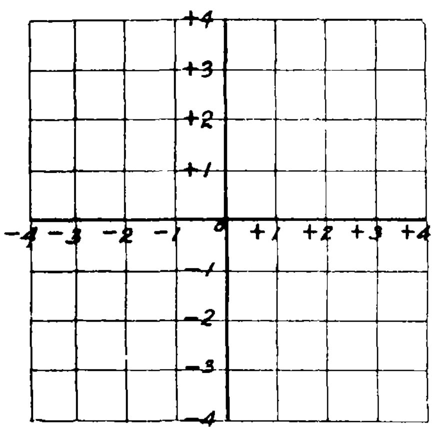


FIG. 160.

839. In a curve diagram, the sense of the factor plotted along the vertical axis can be shown by taking **the distances above the zero point to represent positive values, and those below the zero point to represent negative values.** Similarly, the sense of the factor plotted along the horizontal axis can be shown by taking **the distances to the right of the zero point to represent positive values, and those to the left of the zero point to represent negative values** (*vide* Fig. 160).

THE SINE CURVE

840. In all cases of periodic motion the magnitude of the component factors as time elapses can be illustrated

by sine curves. Thus, the variation in the speed of a swinging pendulum as time elapses may be represented by a sine curve, also the variation of current in an oscillatory circuit as time elapses may be represented by a sine curve.

In many practical cases the curve representing actual values measured will be considerably distorted from the true sine form on account of other factors coming into play, but it will be sufficiently accurate for the purpose of this book, and very much simpler, if we consider that the values of the component factors of all periodic motions follow a simple sine law.

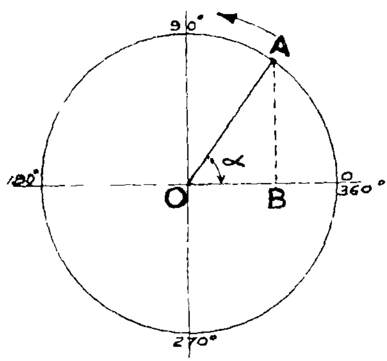


Fig. 161.

841. A sine curve may be constructed as follows. Suppose a point A, Fig. 161, moves at a uniform rate round a circular path in the direction indicated by the arrow; then it is evident that while the point A is travelling round the circle, the angle α will uniformly increase from 0° to 180°, and then to 360°, *i.e.* back to 0°.

842. Now the length of the perpendicular line AB drawn from the point A to the horizontal axis of the circle is proportional to the "sine" of the angle α, because sine $\alpha = \frac{AB}{OA}$, and OA remains constant throughout the revolution. It will be seen that as the point A revolves, the length of this line AB varies from zero at the instant

when the point A is at 0° to a maximum length equal to OA when A is at 90°, back to zero when A is at 180°, then to another maximum when A is at 270°, and finally back to zero when A has reached 360° or 0° again. To distinguish between the lengths above the horizontal axis and those below, all the values of AB from 0° to 180° are positive, or above the horizontal, and all those from 180° to 360° are negative, or below the horizontal.

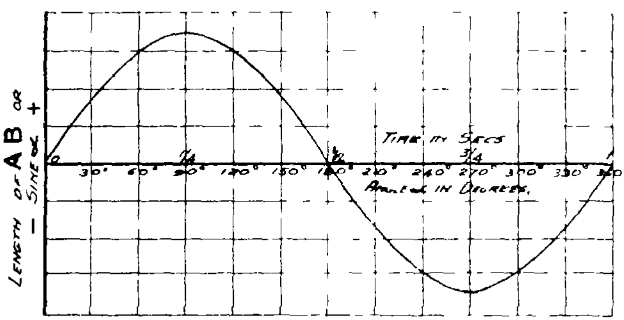


Fig. 162.

843. Now it will be noticed that although the point A is revolving at a uniform rate, the length of the line AB is not varying at a uniform rate; its length increases rapidly at first, then more and more slowly, until, when A is nearing 90°, its length remains nearly constant. Then after A has passed 90°, its length starts decreasing, slowly at first, then more and more rapidly, until, when A is at 180°, its length is zero, and so on.

844. If then we plot a curve illustrating the variation in the length of the line AB by plotting the values of its length along the vertical axis, and time elapsed along the horizontal axis, the curve will take the form shown

in Fig. 162. Since the length of the line AB is proportional to sine *a* (*vide* paragraph 842) the distances along the vertical axis may also represent the values sine *a*; and since the angle *a* is proportional to the length of time that the point A has been moving the distances along the horizontal axis may also represent the values of the angle *a*.

ILLUSTRATION OF TWO OR MORE CURVES ON ONE DIAGRAM

845. When the magnitude of two or more different factors both bear a relation to one another, and also to the variation of a common factor, it is frequently desirable to know the instantaneous values of the various factors concerned. If in such a case the values of the common factor be plotted along, say, the horizontal axis, and the values of the other factors be plotted along the vertical axis, then we shall get two or more curves each illustrating the relation between the common factor and one of the other factors. This will enable us not only to obtain the instantaneous values of all the factors concerned, but will also give us a general idea of the relation which each factor has to the other.

846. Let us take, for example, the experiment described in paragraphs 822 to 824, where we showed that the flow of water from a full tank into an empty tank through a connecting pipe followed the logarithmic law, and the curve illustrating the function, flow and elapse of time, was shown in Fig. 155. Now there is another factor which also varies in relation to the same length of time, namely, the **quantity** of water which has flowed from the full tank into the empty tank, and it is quite conceivable

that we should wish to know at any instant not only what was the rate of flow of water at that instant, but also what was the total quantity of water which had flowed.

847. It is evident that at the commencement of the experiment the quantity of water which had flowed would be zero, and that as time elapses this quantity of water would get greater and greater so long as water is flowing. Therefore the curve representing the quantity of water will start at zero, and will slope upwards indicating an increase in the quantity (*vide* paragraph 811). It is also evident that the rate at which the quantity increases is proportional to the flow of water into the tank. And since the flow of water into the tank is quickest to commence with, and gradually falls off until it nearly, but never quite, reaches zero, it follows that the **rate** at which the quantity of water increases will be greatest at the beginning of the experiment, and will gradually fall off, always approaching but never reaching a definite maximum value.

848. Since we are plotting quantity of water along the vertical axis, it follows that the slope of this curve will be steepest at the commencement of the experiment, and will gradually fall off until it becomes horizontal after an infinite length of time; in this case, the curve will be a logarithmic curve (*vide* Fig. 156).

849. Now the increase in the quantity of water bears a definite relation to the rate at which the water is flowing from one tank to the other during the same period of time, and since each function has a common factor, namely, elapse of time, we can more conveniently compare the effect which one factor has on the other, and

also more conveniently ascertain simultaneous value of time. flow of water and quantity of water which has flowed, by plotting the two curves on the same sheet as shown in Fig. 163.

850. In the case of both curves, the horizontal axis will represent elapse of time, while the vertical axis will

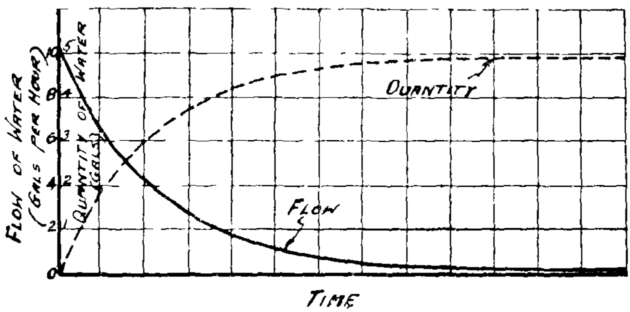


Fig. 163.

represent gallons, in one case, and flow, that is gallons per hour, in the other case.

851. When more than one curve is represented in one diagram, it is sometimes convenient to distinguish between them by drawing them either with different coloured ink or different forms of line. Thus in Fig. 163 the curve representing flow of water is drawn with a full line, and that representing quantity, with a dotted line.

THE THEORY OF THE DYNAMO

852. Dynamos can be classified broadly under two headings, namely, **Alternating Current Machines,** commonly known as Alternators, and **Continuous Current Machines.** The principles underlying both are the same, but the method of applying these principles in the design of the machine varies according to the results required.

In Part I., par. 98 to 117, we showed how a current of electricity can be induced in a coil of wire by causing relative movement between the coil and a magnetic field. Since the current only flows as a result of a difference in potential at the two ends of the coil, it is more correct to say **that a difference in potential or an electromotive force (E.M.F.) is induced in the coil by causing relative movement between the coil and a magnetic field.**

853. A dynamo is an apparatus for producing an E.M.F. by rotating a coil or a number of coils in a magnetic field.

Meaning of Conductors cutting Magnetic Lines of Force

854. In par. 102 we explained that the production of current or, as we shall now consider it, of an electro-

motive force in a coil of wire by electro-magnetic induction, is due to a change in the number of magnetic lines of force passing through the coil, and we described a few simple experiments to illustrate this point. In that explanation we took this point of view as being the easiest for the purpose of explaining the theory of an induction coil. In explaining the action of the dynamo, however, it is easier to take the view that the **E.M.F. is produced by the conductors of a coil cutting the magnetic lines of force.**

The following experiments will illustrate what is meant by a conductor **cutting** the lines of force, and at the same time show that this is, in effect, the same as causing a change in the number of magnetic lines passing through a coil.

855. Fig. 164 shows a coil of wire C, consisting of a single turn, the ends of which are connected to a galvanometer G, which will serve to indicate roughly the amount and the direction of any current which is induced in the coil.

Threaded through this coil is a permanent magnet M, with an air gap A; the lines of force produced by the magnet being shown by dotted lines, and the direction of these lines (*vide* Part I. paragraph 82) by the arrow heads. It is clear that when the coil is in the position marked C all the lines of force pass through the coil. If now we move the coil across the air gap until it occupies the position C_2, we shall have caused a change in the number of lines passing through it, because in the position C_2 no lines of force pass through the coil. Now, while the change in the number of lines passing through the coil is taking place, that is to say, while the coil is travelling through the air gap, an E.M.F.

will be induced in the coil resulting in a deflection of the needle of the galvanometer.

856. Let us look upon the same experiment from the point of view of making one of the conductors, forming the coil, cut the magnetic lines of force. If

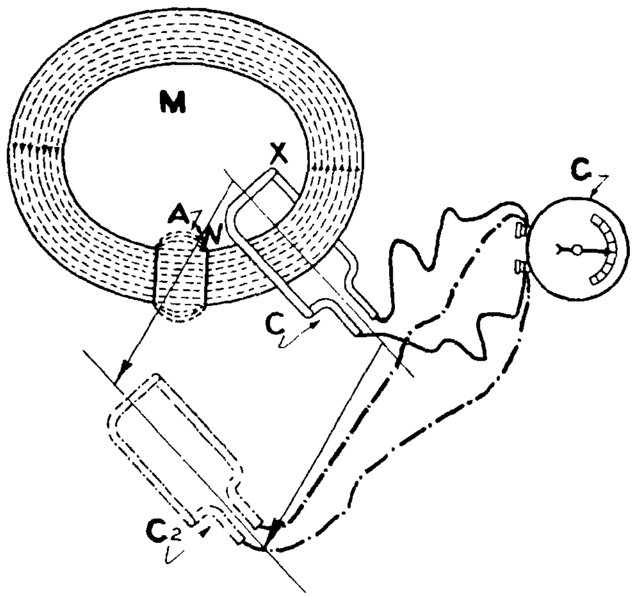


Fig. 164.

we imagine the lines of force as so many threads of cotton passing from one pole of the magnet to the other, it is obvious that, in withdrawing the coil to the position C_2, that side or conductor of the coil WX must sever all these threads; thus can the conductor be considered as cutting the magnetic lines of force. It should, however, be understood that the magnetic lines

are not actually severed. In reality they actually pass through the conductor, so the magnetic field is never actually destroyed.

857. We may say, then, that an E.M.F. will be induced in a coil of wire when the conductors, forming that coil, are made to cut the lines of force in a magnetic field, or, in other words, that **an E.M.F. will be induced in a conductor when that conductor is moved in the magnetic field in a direction across the lines of force,** as shown diagrammatically in Fig. 165.

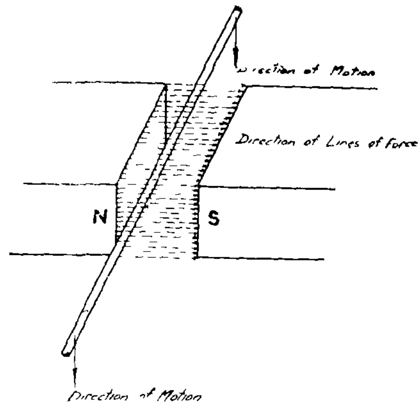


Fig. 165.

Direction of the Current Induced

858. If the two ends of the conductor be connected together to form a circuit, a current will flow in that circuit as a result of the E.M.F. generated, and the direction of that current can be determined by two things, namely, (1) the direction of the magnetic lines of force, and (2) the direction of motion of the conductor.

859. Fig. 166 shows the relation between the direction of the magnetic lines, the direction of motion of the conductor, and the direction of the resulting current

induced. An easy way to remember these relative directions is by placing the thumb, forefinger, and second finger of the **right** hand at right angles to one another, as shown in Fig. 167; then, if the thumb indicates the direction of motion, and the first finger the direction of the lines of force or flux, the second finger will represent the direction of the current induced.

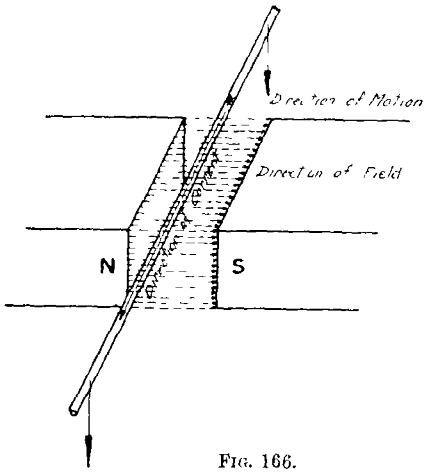


FIG. 166.

860. By applying this rule to various cases it will be seen that the direction of the current in the conductor will be altered if *either* the direction of the magnetic lines or the direction of motion be reversed. But if *both* the direction of motion and the direction of the lines be reversed, then the direction of the current induced in the conductor will remain the same.

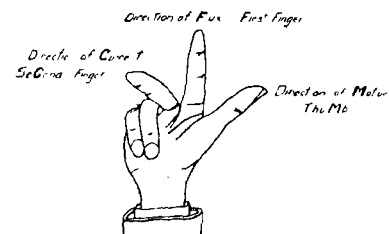


FIG. 167.

In order to illustrate all these effects more clearly,

let us take five cases of a coil of wire moving in a magnetic field, as illustrated in Figs. 168, 169, 170, 171, and 172.

861. In Fig. 168 the coil, forming a closed circuit, is moved, in a uniform magnetic field, from the position A **along** magnetic lines of force to the position B. In this case no current will be generated in the coil because no change has been effected in the number of lines of force passing through it. It is equally true to say that no current is generated in the coil because the conductors forming the coil do not cut the magnetic lines.

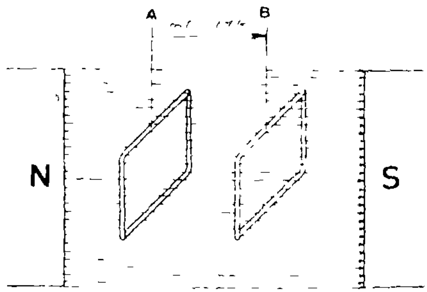


FIG. 168.

862. In Fig. 169 the same coil is moved again in a uniform magnetic field from the position A **across** the lines of force to the position B.

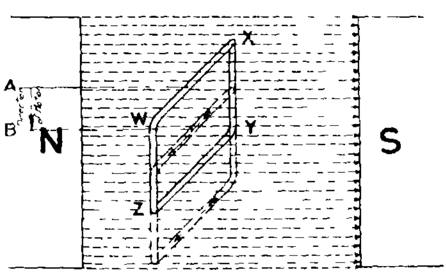


FIG. 169.

In this case again no current will be generated in the coil because no change has been caused in the number of magnetic lines passing through it; but since the conductor forming the coil has been made to cut magnetic lines, it appears, at first sight, that a current should

be induced on this account. If, however, the effect of different portions of the coil cutting the lines be carefully analysed by the help of paragraph 859, it will be seen that the current which tends to flow in the top conductor of the coil, WX, as a result of its cutting magnetic lines, is in an anti-clockwise direction looking at the coil from the south pole of the magnet, while the current which tends to flow in the bottom conductor, YZ, of the coil is in a clockwise direction as indicated by the arrows. Thus the two currents, or rather the two E.M.F.'s which are induced in the coil, neutralise one another, with the result that no current flows.

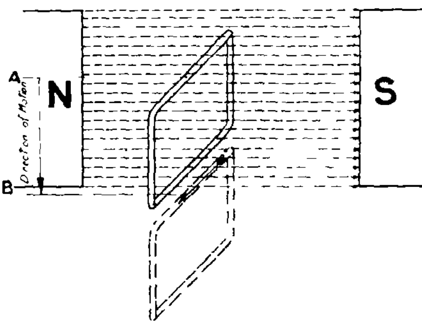


FIG. 170

It is evident also that no E.M.F. is generated in either the conductor XY or WZ, because these conductors are not moving across the magnetic field **in a direction across their length.**

863. In Fig. 170 the same coil is moved in a magnetic field from the position A inside the magnetic field across the lines of force to the position B outside the magnetic field. In this case a current will be generated in the coil because there is a change in the number of magnetic lines passing through it. It is equally true to say that the current will be generated, because whereas the top conductor of the coil cuts the magnetic lines, the bottom conductor of the coil moves outside the magnetic field

and therefore does not cut any lines of force. Thus in this case as distinct from that shown in Fig. 169, no opposing E.M.F. is induced in the bottom conductor, and a current will flow due to the E.M.F. generated in the top conductor.

864. In Fig. 171 the same coil is moved in two magnetic fields, these two magnetic fields being arranged so that *the direction of the lines of force in the one is opposite to the direction of those in the other.* In this case the coil is moved from the position A when it embraces the first field, across the magnetic lines of force to the position B when it embraces the second field. In travelling from one position to the other, it will be seen that the top conductor of the coil is cutting one field in a certain direction, while the bottom conductor is cutting an opposite field in the same direction. Thus the E.M.F. generated in the top conductor is tending to cause a current to flow in the same direction as that generated in the bottom conductor. In this case, therefore, a current will be induced in the coil.

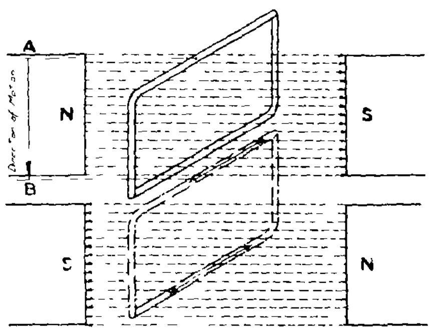


FIG. 171.

Taking again the point of view of the change of the number of magnetic lines passing through the coil, if we consider the magnetic lines of force passing through the coil when in the top field as being positive, and those

in the bottom field as being negative, and if in each case the number of lines threading the coil is then 6, then the change in the number of lines between the two positions will be the difference between +6 and −6, that is to say, a difference of 12.

865. Fig. 172 shows a coil which is rotated in a uniform magnetic field about its axis from the position A to the position B. In this case a current will be induced in the coil, because when in the position A the magnetic lines pass through the coil; but when in the position B no magnetic lines pass through it, as the coil is then lying along the magnetic field. Therefore a change has been caused in the number of magnetic lines passing through the coil.

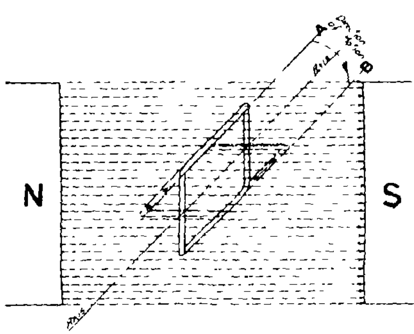


Fig. 172.

Looking at it from the point of view of cutting magnetic lines, it will be observed that, while the top conductor is cutting the lines of force while travelling in a downward direction, the bottom conductor of the coil is cutting the lines of force while travelling in an upward direction relatively to the field, but the direction of the lines of force is the same. *Therefore the* E.M.F. induced in the top conductors will be in the same direction as the E.M.F. induced in the bottom conductors, with a result similar to that obtained in the experiment illustrated in Fig. 171.

Relation Between E.M.F. Magnetic Field and Rate of Cutting

866. If, in the experiment illustrated in Fig. 164, we connect across the coil a galvanometer or other suitable instrument which will denote by its deflection the relative values of E.M.F. generated, we have a means of determining the relation between the **rate of motion, the strength of magnetic field,** and **the E.M.F. produced.**

867. If we move the coil across the field, first slowly and then rapidly, it will be found that **the faster the coil is moved, the greater the E.M.F. produced.** Again, if the coil be moved at a definite speed, first through a weak magnetic field and then through a strong magnetic field, it will be found that a **greater E.M.F. is produced when moving it through the stronger field.**

868. The stronger the magnetic field, the greater the number of magnetic lines of force passing through it. Therefore the conclusion we may draw from these experiments is that the **E.M.F. produced by a conductor cutting lines of force is proportional to the rate at which the magnetic lines are cut,** or, in other words, to the **number of lines cut per second.**

This rule can be stated as an equation, thus :

$$\text{E.M.F.} = \frac{\text{total number of lines of force}}{\text{time in which lines are cut}};$$

or where $\text{N} = $ total number of magnetic lines, $t = $ time taken to cut the lines, then $\text{E.M.F.} = \frac{\text{N}}{t}$.

869. For example, let us suppose that a conductor is made to cut a uniform magnetic field having a total of 1000 lines of force in two seconds, then by applying

our equation we get E.M.F. $= \frac{1000}{2} = 500$. Again, if the conductor be moved twice as fast, that is to say, if it takes only one second to move across the field, then in this case E.M.F. $= \frac{1000}{1} = 1000$.

870. In the experiments illustrated in Figs. 171 and 172, we showed how the E.M.F. produced in the top conductor of the coil assisted the E.M.F. produced in the bottom conductor. Therefore in those cases the total E.M.F.'s produced in the coils are equal to the sum of the E.M.F.'s produced in the top and bottom conductors. Similarly, by repeating the experiments described in paragraphs 861 to 865, but using coils consisting of several conductors, it can be shown that **when a number of conductors cut a magnetic field in such a way that all the induced E.M.F.'s act in the same direction, E.M.F.** $= \frac{N}{t} \times S$, where N = number of magnetic lines of force, t = time in which lines are cut, S = number of conductors cutting the lines.

871. These formulae give the value of E.M.F. in *absolute* units. Since, however, 10^8 absolute units of E.M.F. = 1 volt, then we can express our equation as follows:

$$\text{E.M.F. in volts} = \frac{N \times S}{t} \times 10^{-8}, \text{ or Volts} = \frac{N \times S}{t \times 10^8}.$$

Wave Form of E.M.F. induced in Armature Conductors

872. It is evident that if the strength of the magnetic field is not uniform the above formula will only give the *average value* of the E.M.F. produced during a

certain time, because in such a case the rate of cutting of magnetic lines at different instants will vary. For the same reason, if the speed of the conductor relatively to the magnetic field be varied during the time t, the formula will only give the *average value* of the E.M.F. produced.

873. Where these conditions prevail, it is necessary to calculate the values of E.M.F. **at different instants,** and the results thus obtained can most conveniently be shown in the form of a curve, the "ordinates" or vertical distances of which are made to represent the E.M.F., and the abscissae or horizontal distances are made to represent time. If the speed at which the conductor moves is uniform, then it is evident that the abscissae may also represent distance travelled. Thus, if the speed of the conductor is 1 inch per second, we can make the distances along the abscissae represent either seconds or inches.

874. Take the case that we have already been considering of a conductor cutting a uniform magnetic field of, say, 12,000 lines, which for the sake of argument we will suppose distributed over 1 inch of length of pole face, and let us suppose that the conductor is made to cut this field at a uniform speed in one second, then it follows that throughout the travel of the conductor the rate of cutting the magnetic lines will be 12,000 lines per second, and therefore E.M.F. (in absolute units) = 12,000 *at any instant*. The "curve" representing this E.M.F. will then take the form of a straight line as shown in Fig. 173, where the ordinates represent the values of the E.M.F., and the abscissae represent either length of time in fractions of a second or distance travelled in fractions of an inch.

875. Let us now take the case shown in Fig. 174 of a conductor being **rotated** in a uniform magnetic field, and analyse carefully what will be the resulting E.M.F. produced at different instants during a complete revolution.

For the purpose of explanation we will suppose that the field in which the conductor is rotated again con-

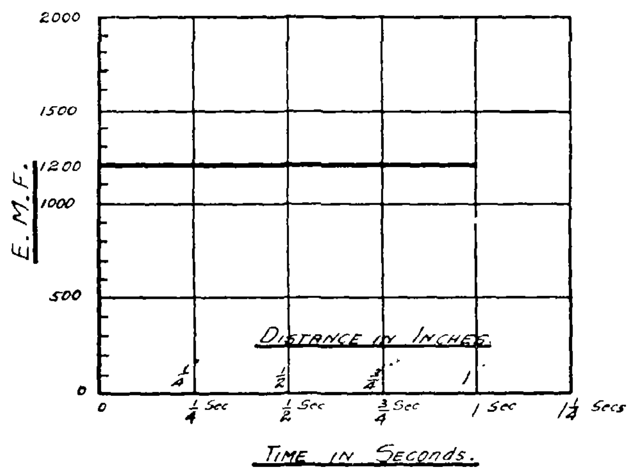


FIG. 173.

sists of 12,000 magnetic lines of force uniformly distributed over the pole face, and that two seconds are taken for a conductor of the coil to make a complete revolution.

876. Fig. 175 shows the same arrangement in a form easier to refer to. N and S represent the North and South Poles of the magnet, and each line drawn from pole to pole represents one thousand magnetic lines of force. The conductor C is shown in section, and travels at a uniform rate along the path shown by the circle,

taking two seconds to complete a revolution and return to its original position. C_1 therefore represents the

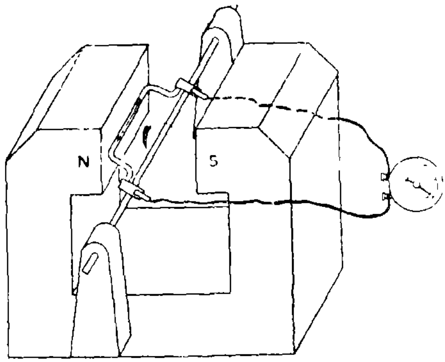


Fig. 174.

position it will occupy at the end of the first $\frac{1}{4}$ second, similarly C_2, C_3, C_4, etc., represent the positions the

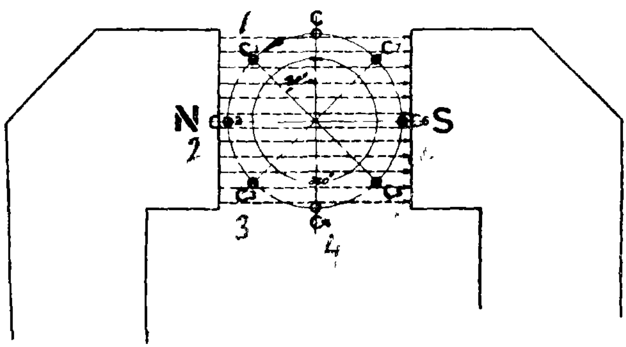


Fig. 175.

conductor will occupy at the end of each successive $\frac{1}{4}$ second.

877. By counting the number of lines the conductor

will cut during each $\frac{1}{4}$ second, it will be seen that during the first $\frac{1}{4}$ second 2 lines are cut, during the second 4 lines, during the third 4 lines, during the fourth 2 lines, during the fifth 2 lines, during the sixth 4 lines, during the seventh 4 lines, and during the eighth 2 lines.

878. By applying our formula, $\text{E.M.F.} = \frac{N}{t}$, and, as each line in the illustration represents 1000 magnetic lines of force, we find that the *average* values of the E.M.F. generated during each fraction of a second are as follows :

Time.	E.M.F.	Time.	E.M.F.
$\frac{1}{4}$ second . .	8,000	$1\frac{1}{4}$ seconds . .	8,000
$\frac{1}{2}$,, .	16,000	$1\frac{1}{2}$,, . .	16,000
$\frac{3}{4}$,, . .	16,000	$1\frac{3}{4}$,, . .	16,000
1 ,, . .	8,000	2 ,, . .	8,000

879. Again, by applying the rule explained in paragraph 859 it will be seen that the E.M.F. generated in the conductor during the first half of the revolution, that is to say, during the first second, will be tending to make a current flow in an opposite direction to the E.M.F. generated during the second half of the revolution, because the relation between the direction of motion of the conductor and the direction of the magnetic lines has been reversed.

880. We may call the positive end of a conductor in which an E.M.F. is generated, that end **towards** which the current tends to flow, and the negative end is therefore that end **from** which the current tends to flow. Therefore, we may say that at that end of the conductor nearest the reader in Fig. 175, a positive (+) E.M.F. is generated during the first half of the revolution, and a

negative (−) E.M.F. is generated during the second half of the revolution.

881. Further, since in passing through a complete revolution, the conductor may be said to have travelled through an angle of 360°, and as it takes 2 seconds to make one revolution, it follows that during each $\frac{1}{4}$ second the conductor will travel through an angle of 45°. If the speed of rotation is constant therefore, it comes to the same thing whether we consider the E.M.F. in relation to time or **in relation to the angular position of the conductor.**

882. We may therefore re-tabulate the values given in paragraph 878 as follows:

Time.	Angular Position of Conductor	E.M.F.	Time.	Angular Position of Conductor.	E.M.F.
$\frac{1}{4}$ second .	45°	8,000	$1\frac{1}{4}$ seconds	225°	− 8,000
$\frac{1}{2}$,, .	90°	16,000	$1\frac{1}{2}$,,	270°	− 16,000
$\frac{3}{4}$,, .	135°	16,000	$1\frac{3}{4}$,,	315°	− 16,000
1 ,, .	180°	8,000	2 ,,	360°	− 8,000

If these values be plotted in the ordinary way, taking the positive values above the horizontal line, and the negative values below the horizontal line, the curve, showing the resulting E.M.F., will take the form shown in Fig. 176.

883. These values, however, do not truly represent the results which would be obtained by revolving the conductor at a uniform speed in a uniform magnetic field for the following reasons:

In arriving at our values of E.M.F. we have supposed, for simplicity of explanation, that the rate of cutting of the magnetic lines **has been uniform throughout each $\frac{1}{4}$ second.** In reality, however, the rate of cutting is varying during each fraction of a second. Thus

at the beginning of the first second, *i.e.* at 0°, the conductor is practically moving parallel to the lines of force, and is therefore not cutting any lines. As it moves further round the circle, however, it cuts gradually more and more lines during each fraction of a second, till it reaches a maximum *rate of cutting* at 90°. From this point the rate of cutting falls off until it reaches zero again at 180°, when once more the con-

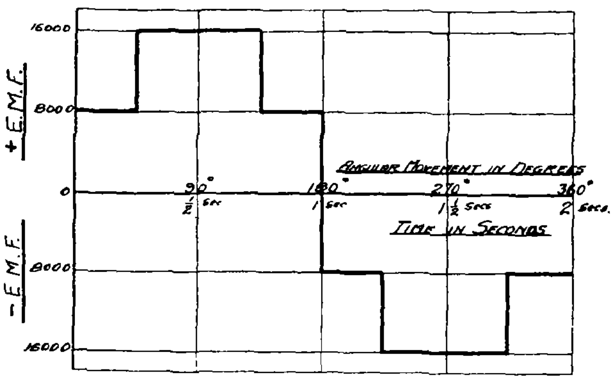


Fig. 176.

ductor is moving practically parallel to the direction of the lines of force; at this point the rate of cutting begins to increase again, although now the conductor is cutting the lines in the opposite direction, till it reaches a negative maximum at 270°, at which point the rate of cutting again falls off till it comes to zero at 360°. If therefore, instead of taking our values of E.M.F. at eight intervals of ¼ second each, we take them at thirty-two intervals of $\frac{1}{16}$ second each, we shall get a much nearer approximation of the true values of the E.M.F. generated in the conductor at different instants of its revolution. It will

then be found that the curve takes the form of a "sine" curve as shown in Fig. 177.

884. When the E.M.F. generated is constantly varying from a positive maximum to a negative maximum, as described in the foregoing paragraphs, it is known as an **alternating E.M.F.,** and the current produced in a circuit as a result of this E.M.F. is known as an **alternating current**, usually denoted by the letters **A.C.** One com-

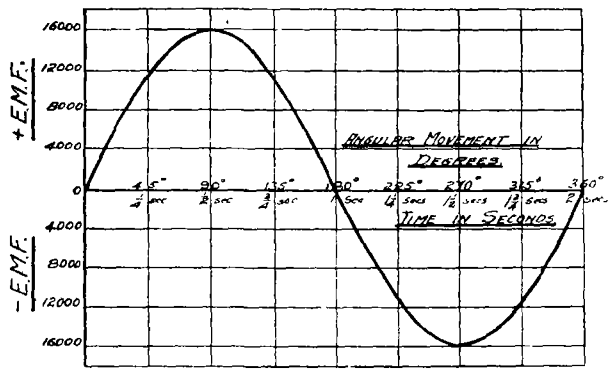


FIG. 177

plete alternation as shown in Fig. 177 is known as a cycle, and the number of cycles per second which are produced is known as the **frequency.** A dynamo which generates an alternating E.M.F. is known as an **alternator.** That part of the dynamo which produces the magnetic field is known as the **Field Magnet,** and that part of the dynamo which carries the conductors in which the E.M.F. is generated is known as the **armature.**

885. From our formula E.M.F. $= \frac{N}{t} \times S$ it is evident that for a given speed, and for a given size or area of

pole face, we can increase the E.M.F. generated by the dynamo in three ways, *firstly*, **by increasing the density of the field,** *and secondly,* **by increasing the number of conductors in the armature,** and thirdly by increasing the speed.

Effect of the Density of the Field

886. By referring to Fig. 175, it will be seen that the distance between the two pole faces of the magnet must be slightly greater than twice the radius at which the conductor is being rotated, in order to allow the conductor to revolve without touching the pole faces.

887. We have previously shown that for a given magnetising force the total number of magnetic lines produced in a magnet of a given area will depend upon the reluctance of the magnetic circuit, and also that the greater part of the reluctance in a magnetic circuit of ordinary dimension is due to the air gap. It is clear therefore that, **by reducing the air gap** between the poles, we can get a greater density and therefore a greater total number of magnetic lines with the same magnetising force.

888. This air gap can be reduced in two ways, firstly, by shaping the pole faces in a curve so that they are parallel to the path of rotation of the conductor, and secondly, by filling up the space inside the path of the conductor, that is to say, filling up the core of the armature, with iron. Such an arrangement is shown in Fig. 178, where, as is usual in most dynamos, the conductors are shown actually embedded in slots in the iron core, thus reducing the gap between the iron of the pole face and the iron of the armature core to a minimum.

889. Besides increasing the density of the magnetic

field, this will, to a certain extent, **alter the distribution of the magnetic lines of force,** with the result that the E.M.F. generated by rotating the conductor through a complete revolution will not exactly follow the sine curve shown in Fig. 177. In practice the curve representing the values of E.M.F. generated during a revolution of the armature will take more or less irregular forms, though always approximating the sine curve. Such a curve when taken for any particular alternator is known as the **wave form of the E.M.F.** of the machine.

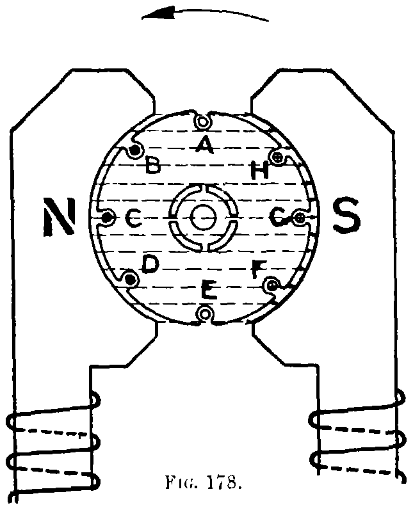


Fig. 178.

To increase the Number of Conductors

890. Up to the present we have considered the case of a single conductor rotating in a magnetic field, but if instead of rotating one conductor we distribute a number of separate conductors evenly round the core of the armature and rotate them together, alternating E.M.F.'s will be generated *in each conductor,* all having an exactly similar wave form **but differing in phase.** This difference in phase is due to the fact that at any

given instant the relative positions of the conductors in the magnetic field are different. For instance, taking the position of the armature shown in Fig. 178, the conductor A is only just commencing to cut magnetic lines, and therefore at this moment the E.M.F. generated in that conductor is at its minimum, whereas at the same instant the conductor C is in the centre of the Field and is therefore cutting lines at the maximum rate, and therefore at the same moment the E.M.F. generated in that conductor is at its maximum. Further the E.M.F.'s generated in the conductors F, G, and H are actually in the opposite direction.

In Fig. 178 the conductors under the North Pole are marked "positive," and those under the South Pole are marked "negative," showing the directions of the E.M.F. generated in each conductor at the particular instant illustrated. For by applying the rule in paragraph 859 and taking the direction of motion of the armature and the direction of the magnetic field, as indicated by the arrow in the diagram, the direction of E.M.F. generated in the conductors under the North Pole will be towards the reader, and similarly the direction of E.M.F. in the conductors under the South Pole will be away from the reader.

891. Therefore, when winding an armature with more than one conductor, we must take into consideration the fact that not only is **the value of the E.M.F. generated in each conductor different** at any given instant, but also that **the E.M.F.'s generated in the conductors which happen to be under the North Pole at that instant are in an opposite direction to the E.M.F.'s generated in the conductors under the South Pole.**

892. Fig. 179 shows the curves of the E.M.F.

generated in three of the conductors, namely A, B. and F. We have chosen these three conductors, because two of them, namely A and B, are adjacent to one another, and the third one, F, is diametrically opposite B. In these curves the E.M F., instead of being plotted

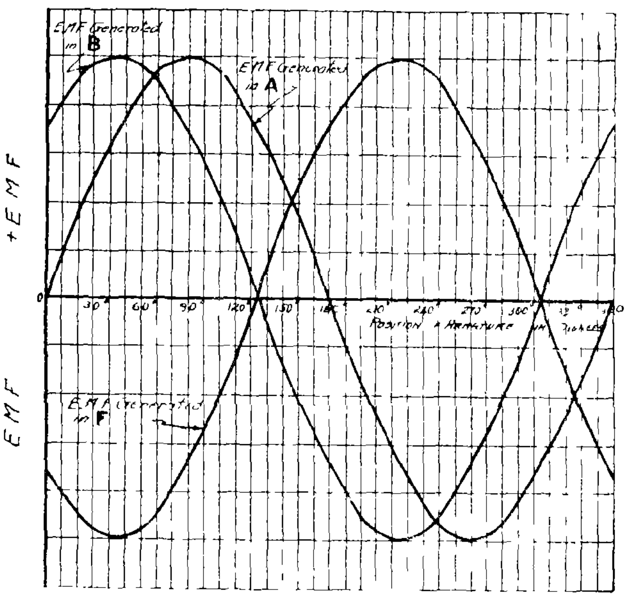


Fig. 179

against time, is plotted against the angle of rotation as being the more convenient. From a study of these curves it will be seen that there is a phase difference of 45° between the E M.F. generated in the conductor A and that generated in the conductor B, and a phase difference of 180° between the E.M.F. generated in the conductor A and that generated in the conductor E.

Inter-connection of Armature Conductors

893. There are two possible ways of connecting the conductors of an armature in series to obtain the maximum resultant E.M.F. Either a conductor must be connected to the one immediately adjoining it, or it must be connected to the one diametrically opposite to it. That is to say, in Fig. 178 the conductor marked "B" can either be connected to the conductor immediately adjoining it (in this case either A or C), or it can be connected to the conductor immediately opposite to it (in this case the conductor marked F). The method of connecting, however, will be different in the two cases for the following reasons.

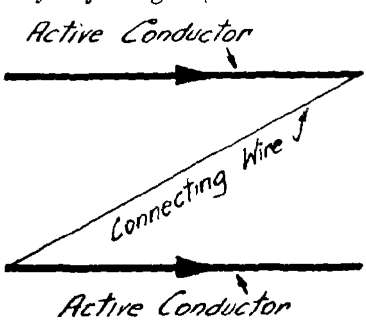


Fig. 180.

894. If the E.M.F.'s in the two conductors shown by the thick lines in Fig. 180 are in the relative direction shown by the arrowheads, then it is obvious that **in order that the two E.M.F.'s assist each other,** they must be connected **diagonally** as shown by the thin line.

Similarly, if the E.M.F.'s in the two conductors are in the relative directions shown in Fig. 181, then they must be connected **across** as shown again by the thin line.

If they are otherwise connected, it is evident that the two E.M.F.'s will oppose and thereby neutralise one another.

895. If now we apply this rule in connecting up the several conductors of an armature, we get two distinct arrangements, shown respectively in Figs. 182 and 183.

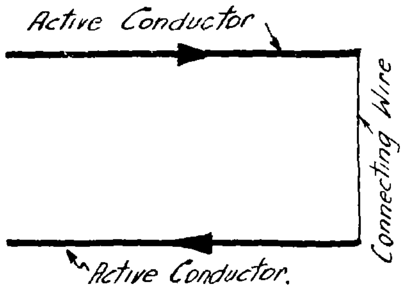


FIG. 181.

896. In Fig. 182 **opposite conductors are connected together,** and in this case it is evident that the relative directions of the E.M.F.'s in the two are as shown in Fig. 181. The connecting wires can therefore be brought across the end of the armature core as shown. An armature wound in this way is known as a "**drum**"**-wound armature.**

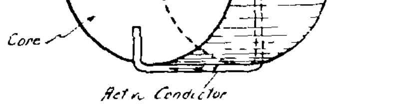


FIG. 182.

897. In Fig. 183 **adjoining conductors are connected together,** and in this case it is evident that the relative directions of the E.M.F.'s in the two conductors will be as shown in Fig. 180, and they must therefore be connected diagonally; but since, if the connection were brought across the face of the armature, **an E.M.F. would be generated in the connecting wire** which would be opposite in direction to the E.M.F. of the two

conductors, the only practicable way is to construct the armature core in the form of a cylindrical iron ring and to bring the connecting wire **through the centre** of the ring as shown in Fig. 183, while the conductor itself lies across the **outer face** of the ring. If this is done, no E.M.F. will be generated in the connecting wire, because all the magnetic lines of force will pass from the North Pole to the South Pole of the field magnet **through the iron ring,** as shown in Fig. 184, and therefore only the conductors on the outside face of the ring will cut the magnetic lines. Such an armature is known as a "**ring**" - **wound armature.**

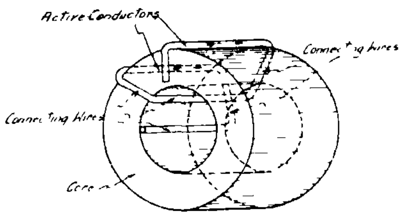


FIG. 183.

898. If we connect in series all eight conductors of a ring-wound armature, starting from the conductor A and finishing at the conductor H, as shown in Fig. 184, the resultant E.M.F. will **always** be *zero* in all positions of the armature, because in every position of the armature an equal number of turns will be under both North and

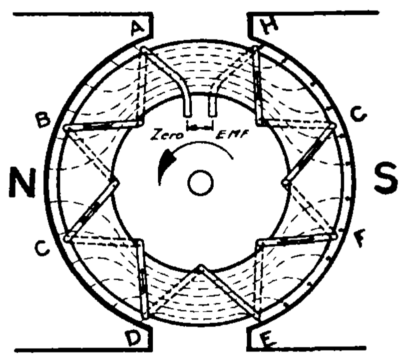


FIG. 184.

South Poles at the same time, consequently there will always be equal and opposite E.M.F. generated in opposite sides of the armature.

899. This can be easily proved with the aid of the E.M.F. curve shown in Fig. 177 by adding up all the instantaneous values of E.M.F. generated in the several conductors in various positions, having regard to their direction, *i.e.* whether + or –, when it will be found that in every case the same amount of "positive" and "negative" E.M.F. will be generated in the winding. Therefore the resultant E.M.F. across AH with this arrangement will **always** be zero.

900. If, however, we only allow the windings of the armature to occupy one-half of the circumference, as shown in Fig. 185, then it will be found that the resultant E.M.F. will not be zero in **all positions** of the armature. Thus, when the armature is in the position shown in Fig. 185, all of the conductors of the winding are under the North Pole, and consequently all the E.M.F.'s in the different conductors are assisting one another, with the result that in this position the E.M.F will be at a maximum. On the other hand, when in the position shown in Fig. 186, two of the armature conductors, A and B, are under the North Pole, and two, C and D, under the South Pole, consequently in this position the resultant E.M.F. will be zero.

901. When the armature is in the position shown in Fig. 187, the resultant E.M.F. will again be at a maximum, because once more all of the conductors are under the same pole; but as in this case they are under the South Pole, it is evident that the resultant E.M.F. will be in the opposite direction to what they were under the North Pole, as shown in Fig. 185.

Again, when the armature is in the position shown in Fig. 188, the resultant E.M.F. will once more be zero because an equal number of the conductors are under the North and South Pole.

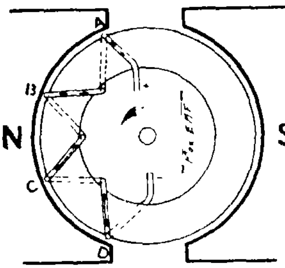


FIG. 185.

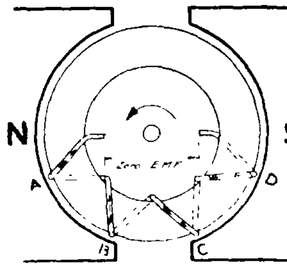


FIG. 186.

902. It is evident, therefore, that when such a coil is rotated between two field poles, **an alternating E.M.F. will be induced across its terminals which will pass through one cycle for every complete revolution of the**

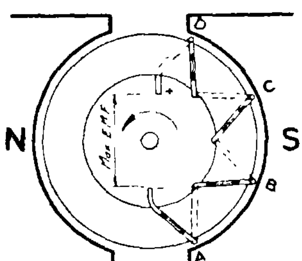


FIG. 187.

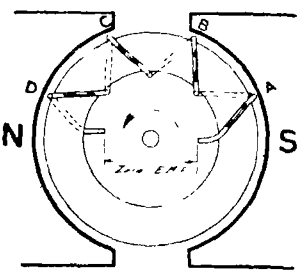


FIG. 188.

armature. It is also evident that the wave form of this E.M.F. will be similar to that of each conductor separately, but the maximum value of the E.M.F. across the whole winding will be greater than that across each conductor separately in proportion to the

number of conductors in series constituting the winding.

903. There is no reason why a similar series of conductors cannot be wound on the other half of the armature ring, as shown in Fig. 189, in which an alternating E.M.F. will also be induced when the armature is rotated; but in this case the E.M.F. generated in the second winding will be 180° out of phase with that generated in the first winding. That is to say, in Fig. 189, if the end A of the first coil is positive and consequently the end D negative at a certain moment, then the end E of the second winding will be negative and the end H positive at the same moment.

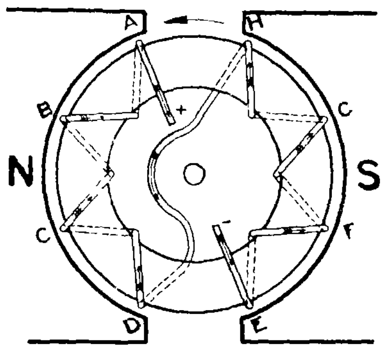


Fig. 189.

904. It is evident, therefore, that if we connect one end of the first coil to the **opposite** end of the second coil, that is to say, if, as in Fig. 189, we connect D to H, we shall have coupled the two coils together **in such a way that the resultant E.M.F. across AE will be equal to the sum of the E.M.F.'s across the half windings AD and EH.**

905. An armature connected in this way is known as an "**open-coil armature,**" because when completed there are two free ends to the armature winding. These free ends are brought to the two "slip rings" mounted on the armature spindle described below.

The Slip Rings

906. Since the armature must necessarily be kept revolving to generate an E.M.F. a method must be devised for connecting the windings of the armature to any desired outside circuit. This is usually accomplished by what are known as "slip rings" and "brushes."

Two brass rings are carried on the shaft of the armature and carefully insulated from each other and from

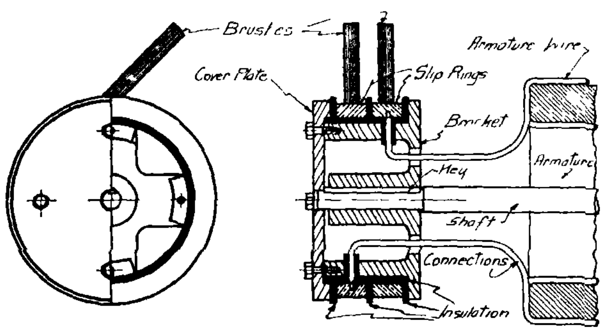


Fig. 190.

the shaft, as shown in Fig. 190. These rings rotate with the armature, but having a smooth surface, connection can conveniently be made to them from a fixed part of the machine by means of copper gauze or carbon "brushes" pressing lightly on the surface of the rings. One end of the armature winding is then connected to one slip ring and the other end to the other slip ring, while the outside circuit to which it is desired to connect the dynamo is connected to the two brushes. Slip rings are usually shown diagrammatically as two concentric circles with a brush pressing on each, thus 

907. Referring again to Fig. 189, another method of connecting up the two coils of the armature presents itself. Instead of connecting the two coils **in series** as shown, we can connect them **in parallel** as shown in Fig. 191.

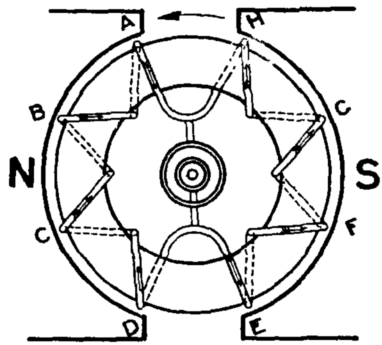


Fig. 191.

908. In this case, the ends of the two coils, A and H, are both connected to one slip ring, and the other ends, D and E, of the two coils are connected to the other slip ring. In this case, the resultant E.M.F. generated would be **only equal** to that generated in each coil separately, which is half the E.M.F. generated when the two coils are connected in series; but since in this case any current we take from the armature would be divided equally between each coil, it follows that although only half the voltage would be generated by the machine, we could yet take twice as much current

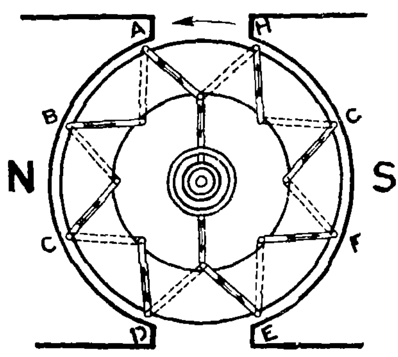


Fig. 192.

from it without overheating the conductors. Since power = E.M.F. × Current, it is evident that the output of the machine will be the same whether we connect the two coils in series or in parallel.

909. Looking at Fig. 191, it is evident that when the two coils are connected in parallel, it is just the same as if the armature were wound with a single continuous coil, as shown in Fig. 192, with tappings taken off at opposite points on the winding; these tappings being connected to the slip rings as before. An armature connected in this way is known as a "closed-coil armature."

Effective Values of Alternatinc E.M.F.'s

910. We have shown that during each cycle an alternating current or an alternating E.M.F. passes through a range of values varying from zero to a certain maximum value.

It must be clearly understood what is meant when it is stated that an alternating E.M.F. of so many volts is generated, or an alternating current of so many amperes is passing through a circuit.

Since the current or E.M.F. is continually varying, **it is necessary that it be defined by some average value.**

911. By universal consent alternating currents are defined in terms of the value of the continuous current which would produce the same energy effect in the circuit.

912. In other words, if a given alternating current, whose maximum value may be, say, four amperes, is passed through a given resistance a certain amount of energy will be absorbed by the resistance and con-

verted into heat. If, however, a continuous current of four amperes were passed through the same resistance it would be found that considerably more energy is absorbed and converted into heat. Now the alternating current would be defined as that value of continuous current which would produce the same amount of heating in that resistance.

913. This average or effective value is considerably less than the maximum value reached in a cycle, but always bears the same relation to the maximum value.

It is known as **the root-mean-square value** because it is obtained by taking the square root of the average square value of all of the ordinates during a complete cycle.

914. It can be shown that **the root-mean-square value of an alternating current which follows a true sine curve is** $\frac{1}{\sqrt{2}}$ **or ·707 of the maximum value.**

915. All measuring instruments, such as Ammeters and Voltmeters, used in connection with alternating current circuits are calibrated to read the root-mean-square or effective value of the amperes or volts.

Determination of Frequency of an Alternator

916. We have now shown briefly how an alternating E.M.F. is induced in each conductor of the armature, and how these conductors can be connected together either in series or parallel, producing a resultant E.M.F. which is also alternating but which has a higher value depending upon the number of conductors thus connected.

917. In the case we have been considering, the field consisted of one pair of poles only, one North Pole and

one South Pole. We showed how in this case one revolution of the armature was necessary to produce one complete cycle of alternating E.M.F. It is easy to follow that the effect of fixing two or more pairs of poles symmetrically round the armature, as shown in Figs. 193 and 194,

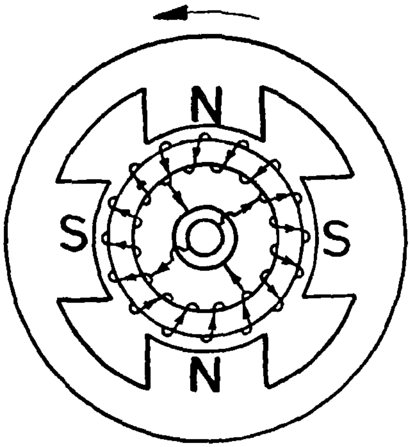


FIG. 193.

will be to produce a complete cycle of alternating E.M.F. for **each pair of poles** under which the conductors travel. Thus in the machine shown diagrammatically in Fig. 193, one revolution of the armature will produce two complete cycles of alternating E.M.F., and similarly, in the

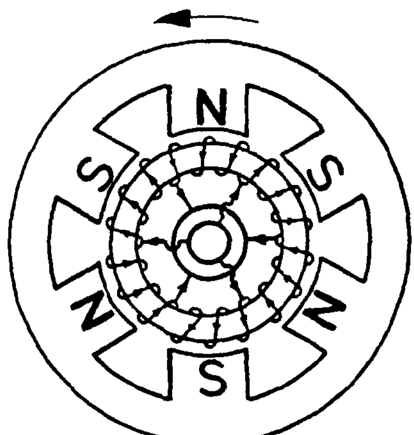


FIG. 194.

machine shown diagrammatically in Fig. 194, one revolution of the armature will produce three complete cycles of alternating E.M.F.

918. Thus, if we know the number of pairs of poles with which a machine is wound, we can calculate the frequency of that machine **by multiplying the speed of the machine in revolutions per second by the number of pairs of poles.**

Example.—If a four-pole machine is running at 1500 R.P.M. the frequency will be $2 \times 25 = 50$ because it has two pairs of poles and revolves at 25 revolutions per second.

THE CONTINUOUS CURRENT DYNAMO

919. Exactly the same principles hold good as regards the E.M.F.'s produced in the conductors of the armature of a continuous current dynamo. That is to say, **alternating E.M.F.'s are produced in the conductors themselves,** but, as we shall show later, these alternating E.M.F.'s, instead of being brought straight to the outside circuit through slip rings as in the case of the alternator, are taken through an apparatus for automatically reversing their direction, so far as the **outside** circuit is concerned, at definite intervals. In order to produce a continuous current in the outside circuit, or, as it may be better considered, in order to produce a continuous E.M.F. at the brushes of the dynamo, **an arrangement is provided for reversing the connections of the armature coils to the brushes at the moment when the E.M.F. induced in the coils reverses.** This arrangement is known as a **Commutator,** and its action is described in the following paragraphs.

920. Let us take the simplest case of a single coil

being rotated, as shown in Fig. 195. If the two ends of the coil, instead of being connected to two slip rings, be connected one to each half A and B of a **divided** ring **which rotates with the armature,** and if the two brushes C and D **be fixed** in the position shown, it is evident that while the coil is travelling under the North Pole of the magnet the half ring A will be in contact with the brush D and the half ring B with the brush C, and similarly, while the coil is travelling under the South Pole of the magnet, A will be in contact with C, and B with D, as shown in Fig. 196.

921. By tracing the directions of the E.M.F. gener-

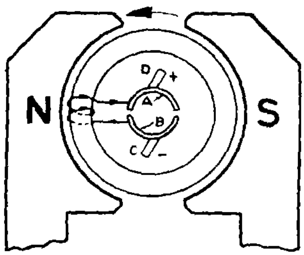


FIG. 195.

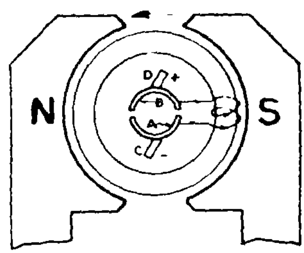


FIG. 196.

ated, it will be seen that while the coil is travelling under the North Pole the half ring *A will be positive* and *B will therefore be negative,* and similarly, while the coil is travelling under the South Pole, *A will be negative* and *B positive.* It follows, therefore, from the conditions described above that **the brush D will always be in contact with whichever half ring is positive, and the brush C with whichever half ring is negative throughout the revolution.**

922. Since the wave form of the E.M.F. generated in the active conductors of the coil takes the form shown in Fig. 177, it is obvious that the curve showing the

value of the E.M.F. at the brushes, when the coil is thus connected to a split ring, will take the form shown in Fig. 197.

923. The same principle can be applied to an armature wound with a number of conductors to form a closed coil winding similar to that described in paragraph 908. In this case the connections to

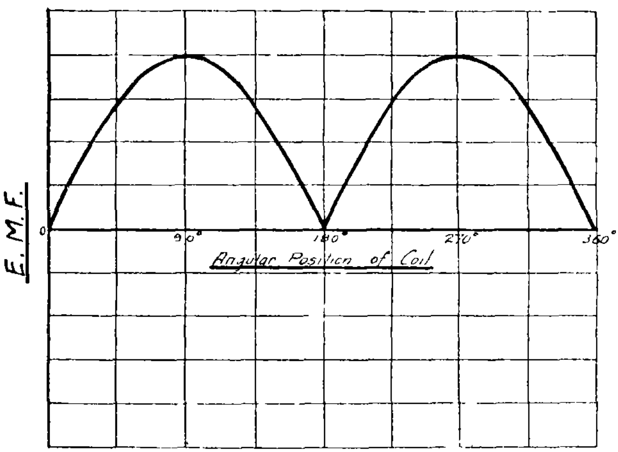


FIG. 197.

the commutator would be as shown in Fig. 198, and the E.M.F. produced at the brushes would again take a similar form to that shown in Fig. 197, except that the maximum value of E.M.F. would be proportionately higher.

924. It will be observed that in these cases, although we get a uni-directional E.M.F. at the brushes, it cannot be said to be "continuous," as it is constantly varying from zero to a maximum value and back

to zero. It can therefore be described better as an impulsive E.M.F.

925. If, instead of taking only two connections off our armature winding, we take four equally spaced connections and connect each to a segment of a four-part commutator, as shown in Fig. 199, we shall get four uni-directional impulses of E.M.F. at the brushes to every revolution of the armature. In this case each impulse will represent a quarter of a cycle, and since the winding of the armature is symmetrical, each impulse will be exactly the same.

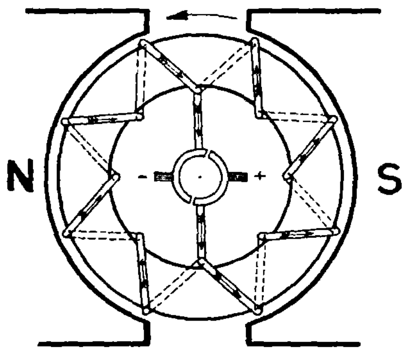


FIG. 198.

ADJUSTMENT OF BRUSH POSITION

926. By adjusting the position of the brushes relatively to the field, **we can arrange to make connection with the winding at any desired point on the E.M.F. curve.** Thus in Fig. 199 if the brushes be placed in the positions shown by the dotted lines, connection will be made to the armature windings at the time when the E.M.F. is at zero, and since the brushes will be in contact with the same commutator segments **for a quarter of a revolution,** it follows that during that time the E.M.F. in the armature, and therefore the E.M.F. across the

brushes, will rise to its maximum value. Just as it reaches its maximum value, however, that is to say, just as it has passed through a quarter of a cycle, or 90°, those particular commutator segments leave the brushes and the next segments take their place. These segments, however, are connected to the armature windings at a point 90° behind the first one, so that the E.M.F. in them at the commencement of contact is again at zero, and the same effect is repeated through each quarter of a revolution. If the E.M.F. at the brushes be plotted, the curve will take the form shown in Fig. 200.

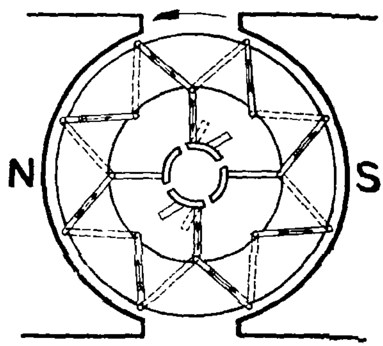


Fig. 199.

927. If now we adjust the position of the brushes so that they commence to make connection with a commutator segment $\frac{1}{8}$ of a cycle, or 45°, before the E.M.F. in these segments is at its maximum, as shown by the full lines in Fig. 199, then it is evident that the curve representing the E.M.F. at the brushes will take the form shown in Fig. 201.

928. It will be observed that in this case we get a result very much nearer a continuous E.M.F. at the brushes than in the case of a two-part commutator, as shown in Fig. 197, and it is evident that by still further increasing the number of commutator segments, we can obtain what is, for all practical purposes,

a perfectly uniform continuous E.M.F. across the brushes.

There is one point to note here as regards the effect of the position of the brushes.

929. By referring to the curves shown in Fig. 200, it will be seen that just at the point where a brush is

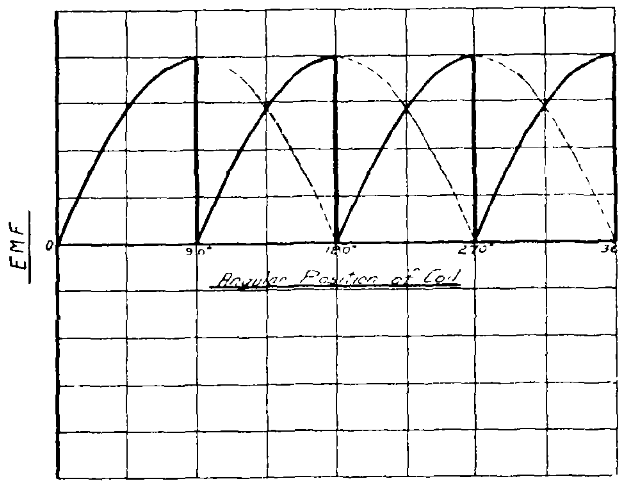


Fig. 200.

leaving one segment and making contact with the next, the E.M.F. in the one segment is at a maximum and in the other at zero.

930. The effect of this will be to cause violent sparking at the brushes particularly when any current is taken out of the armature. This position of brushes is obviously an extreme case, but the same effect will be noticed, only to a less extent, at all the brush positions except the correct one.

Excitation of Dynamo Fields

931. Unless permanent magnets be used for the Field a Dynamo, some arrangement must be made for ducing a magnetic flux through the pole pieces. Except for very special machines, permanent magnets unsuitable; in the first place the magnetic flux

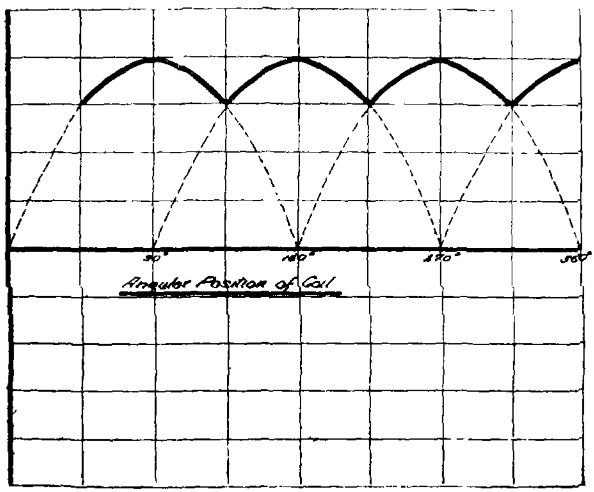


FIG. 201.

nsity is low, thereby necessitating a large amount of el to produce a given amount of flux; secondly, any rrent taken from the armature tends to demagnetise poles owing to reaction, and thirdly, they are expensive. It is usual, therefore, to use **electro magnets** the fields of a dynamo and to divert some of the rrent generated by the armature through the coils the electro magnets.

932. In the case of a direct current machine, this is easily accomplished by winding the magnetising coils of the electro magnets, or field coils as they are called, with a large number of turns of comparatively fine wire, and connecting these coils across the brushes of the dynamo, as shown diagrammatically in Fig. 202.

It will be noticed, however, that with such an arrange-

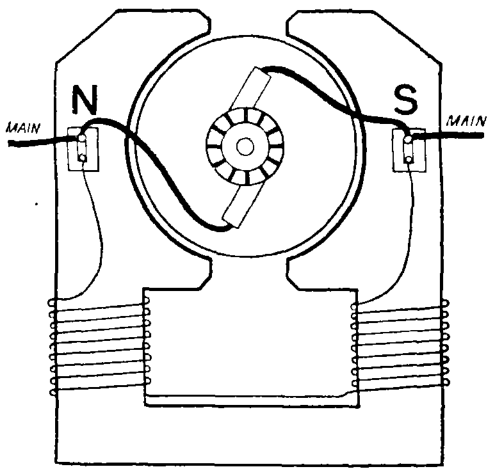


FIG. 202.

ment, should there be no magnetism in the field poles when the dynamo is first run up to speed, no current would be generated by the machine, and therefore a current from some outside source would have to be passed through the field coils to start the magnetism.

933. This, in fact, is always necessary with a new machine when it is run for the first time, but once the fields have been magnetised, the iron forming the field magnets will, owing to the hysteresis of the iron, retain a

small amount of magnetism after the current has ceased to flow through the coils.

934. For this reason, when the machine is run up to speed the second time, a small E.M.F. will be generated in the armature windings, sufficient to start a small current flowing in the magnetising coils. This produces a greater magnetism in the iron which, in turn, produces a larger E.M.F. in the armature, and so the process goes on until the saturation of the iron, forming the field magnets, is such that a further magnetising current results in little or no increase in the number of magnetic lines of force induced, and the E.M.F. generated by the machine then becomes steady. This process is called "building up of field."

935. In order that a dynamo may build up its field, the magnetising force generated by the armature in the field coils must tend to induce lines of force in the field poles **in the same direction as the residual magnetism.**

936. It should be understood that the residual magnetism in the iron is very small compared with the normal magnetism of the field when fully excited, so that the E.M.F. generated in the dynamo windings at the commencement of the building up process is very small. Further, owing to the hysteresis of the iron, **a certain minimum current must flow through the magnetising coils before there is any increase in the number of magnetic lines.** It frequently happens that the brushes make bad contact with the commutator, with the result that the high resistance of this bad contact reduces the flow of current through the magnetising coils.

937. If this reduced current is below the minimum necessary to overcome the hysteresis of the iron, then

it is evident that no increase in the number of magnetic lines will result and the dynamo will not build up its field.

938. Bad contact between the brushes and the commutator may be due to: (1) Brushes sticking in their holders, thereby preventing the brush springs from keeping them pressed on to the commutator; (2) the copper bars of the commutator becoming worn, leaving the insulating material between the commutator bars (which is sometimes harder than the copper) projecting slightly beyond the surface of the commutator; (3) dirt or grease on the commutator

939. In the case of alternators, it is evident that the field windings cannot be connected across the slip rings because the E.M.F. generated is an alternating one which would, at one moment assist, and at another moment destroy the residual magnetism.

940. There is no reason, however, why tappings should not be taken at suitable points on the armature windings and brought to the bars of a commutator mounted beside the slip rings and the field windings be connected to the brushes of the commutator.

In practice, this method of exciting an alternator is frequently used.

941. Another method commonly employed is to have an entirely separate winding threaded in the same slots of the armature as the alternating current windings, these windings being brought to a commutator in the usual way. This method has the advantage of enabling the machine to be designed to generate a direct current at any desired voltage quite independently of the voltage of the alternating current winding, so that in addition to supplying the current to the magnetising coils,

current may be taken for charging accumulators or any other special purpose required.

EDDY CURRENTS

942. We have already shown how the conductors of the armature are imbedded in an iron core in order to reduce the air gap in the magnetic circuit of the dynamo. Obviously this iron core revolves with the conductors in the magnetic field. Since the iron is also a conductor of electricity and is also unavoidably cutting the lines of force induced by the field magnets, the result is that

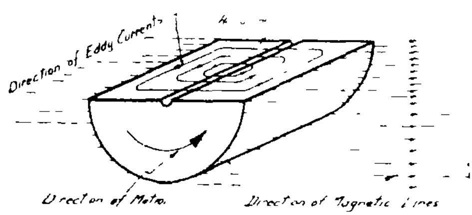


FIG. 203

an E.M.F. is generated in the iron body of the armature which causes currents to circulate continually in the metal. These currents are known as **Eddy Currents,** and since they cannot be utilised they only represent so much **wasted energy,** and in addition, heat up the iron of the armature core to the detriment of the running of the machine. Means must therefore be found of reducing them to a minimum.

The direction of these currents will be found by applying the rule illustrated in Fig. 167 and will be as shown in Fig. 203, that is to say, round the core at right angles to the lines of force.

943. To prevent these currents flowing, armature cores are built up of a large number of thin circular plates of iron separated from one another by very thin paper or varnish. The plates are threaded on to the armature shaft and are clamped together by some suitable means, such as that illustrated in section in Fig. 204. It will be seen that these sheets of paper, being non-conductive, offer a large resistance to any currents which tend to flow in the iron core in the directions indicated in Fig. 203. At the same time they do not increase the reluctance of the magnetic circuit as the lines of force can pass freely down each plate of the armature core without passing through the paper, which is a non-magnetic material, and which therefore also has a high reluctance.

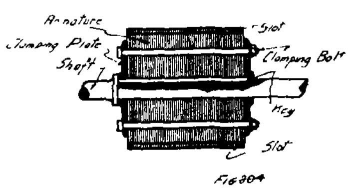


Fig. 204.

944. For the sake of simplicity of explanation, we have discussed only the simplest form of dynamo with the simplest possible winding, but many different methods are employed for winding and connecting up the armature coils or magnetising coils, all of which are designed with some special object, such as cheapening manufacture of the machine, increasing its efficiency, reducing its weight, etc.

945. For the reason that the diagrams illustrating the connections of a ring-wound armature are much simpler to follow than those illustrating the connections of a drum-wound armature, we have confined our remarks in the foregoing paragraphs to the former type of machine. In paragraph 896, however, we mentioned the

fact that by bringing the connecting wire across the end of the armature core, opposite conductors could be joined together to obtain exactly the same results. We also mentioned that armatures connected in this way are known as drum-wound armatures.

946. These differences in the methods of connecting up the several conductors, however, are merely details of construction, and do not in any way modify the theory underlying the action of a dynamo.

For example, in the case of the machine illustrated in Fig. 178, we know that the E.M.F. generated in the conductor B is always exactly in phase with that generated in the conductor F, except that the direction of the two E.M.F.'s is opposite ; therefore, there is no reason why the conductor A should not be connected to the conductor F instead of to B, provided the connecting wire is brought across the end of the armature core, as illustrated in Fig. 182 (instead of through the centre of the armature core, as shown in Fig. 183), thus forming a drum-wound armature instead of a ring-wound armature.

947. Similarly, if we take the case of a multi-pole machine, as, for example, that illustrated in Fig. 205, the conductor A can either be connected to the conductor B, in which case the winding must necessarily take the form of a ring-wound armature ; or it can be connected to the conductor F, in which case the connecting wire must be brought across the end of the armature core, as shown in the diagram, thus forming a drum-wound armature.

948. As a matter of fact, the ring armature is very little used, because it is found that with the other method of winding shorter connecting wires are needed, thus

increasing the efficiency of the machine, and also rendering the process of winding the armature much

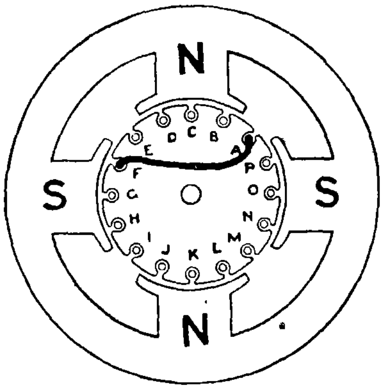


FIG. 205.

simpler, due to the fact that the conductors do not have to thread the armature core as in the case of the ring-winding.

THE THEORY OF THE TRANSFORMER

949. In considering the theory of the Dynamo we took the point of view that an electromotive force is induced in the conductors of a coil when they are made to cut magnetic lines of force, and we showed that this is, in effect, the same thing as causing a change in the number of magnetic lines of force threading the coil.

950. The Transformer is based on exactly the same principles, although they are applied in a different way.

In the case of the dynamo, the effects which we considered were those due to a conductor being moved in such a way as to cut magnetic lines of force produced by a constantly magnetised field magnet. In the case of a transformer, the effects which we shall consider are those due to one conductor, called the **primary**, being placed in such a position near another conductor, called the **secondary**, that the magnetic lines of force induced by a current flowing in the primary conductor cut the secondary conductor.

951. If a current is made to flow through a conductor AB, which we may call the Primary conductor, as illustrated in Fig. 206, then a magnetic field is produced round that conductor, as shown by the dotted lines in the diagram (*vide* Part I. paragraph 85).

952. It follows, then, that if we cause another con-

ductor CD, which we may call the Secondary conductor, to approach the conductor AB, it will necessarily cut the lines of force induced by the current flowing through the primary conductor. An electromotive force will therefore be induced in the secondary conductor which, if the ends of the secondary be joined together to form a circuit as shown,

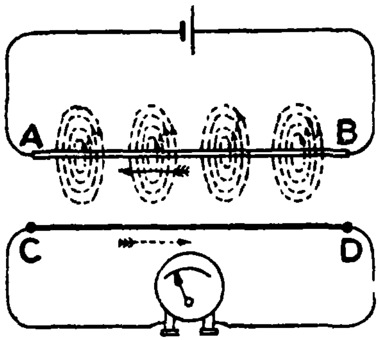


FIG. 206.

will cause a current to flow in the secondary circuit. By applying the rule given in paragraph 859 it will be found that **the direction of the current in the secondary is opposite to the direction of the current in the primary.**

953. It is not, however, necessary to move the secondary conductor if the current in the primary is variable, because exactly the same effect can be produced if we leave the secondary wire permanently close to the primary wire and then cause the magnetic lines of force to cut the conductor.

954. To grasp the idea properly, it is necessary to have a mental picture of how a magnetic field is formed. When a current of electricity is caused to flow through a conductor, the lines of force do not suddenly appear in space around the conductor, but they start out from the conductor itself and rapidly spread in all directions at the speed of light to the limits of the field in much the same way as a circle of ripples spread out from the

point where a stone is thrown into a pond. There is this difference, however, that the lines of force only travel to a definite distance and then stop there, and further if the current inducing them is interrupted, then they immediately converge on their starting-point.

955. Having grasped this elementary conception of the formation of a magnetic field, it will be easy to follow that if we place our primary and secondary conductors close to one another, as shown in Fig. 207, and connect the primary conductor to a battery B through a switch S, then if we suddenly close the switch, allowing a current to flow through the primary conductor, lines of force will be induced, as shown in Fig. 207, most of which must necessarily cut the secondary conductor in taking up their positions.

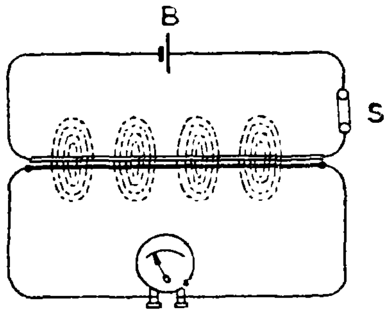


Fig. 207.

956. It will be observed that these lines cut the secondary conductor at right angles to the length of the conductor and at right angles to the direction of the lines of force; therefore, by applying the rule given in paragraph 859, an E.M.F. will be induced in the secondary conductor, which, if its ends be connected together, will cause a current to flow through it **in the opposite direction to that of the primary current.**

957. Now magnetic lines of force take the path of least reluctance, just as a current of electricity will take the

path of least resistance, so that if we provide a path of iron for the magnetic lines induced by a current flowing through a conductor, the majority of these lines will crowd into the iron path, because the reluctance of iron is many hundred times less than that of air.

958. Take the case of a single conductor surrounded by an iron ring, as shown in Fig. 208. The lines of force induced by a current flowing through this conductor will

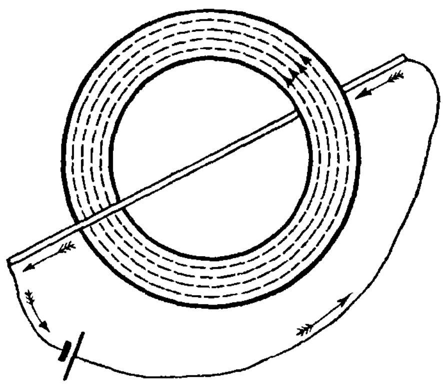


FIG. 208.

not be found evenly distributed round the conductor in the way illustrated in Figs. 206 and 207, but instead they will be found to be crowded together in the iron ring, as shown by the dotted lines in the diagram. But there is this important point to grasp, that **in taking up their position in the iron ring they all traverse the air space between the conductor and the ring,** because, as already pointed out, they all start out from the conductor itself.

959. For example, if we imagine a single turn of wire wound round an iron ring, as shown at A in Fig. 209.

through which a sufficient current is passed to produce a single line of force, that line of force will eventually occupy a position entirely in the iron ring, as shown by the dotted line E in the diagram, but before it reaches this position it has to grow from the conductor, as shown by the lines E_1, E_2, E_3, and E_4, which illustrate successive positions occupied by the line of force during its growth.

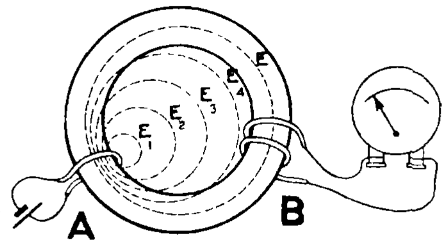


FIG. 209

It is evident, therefore, that any conductor or conductors which embrace the iron ring, as, for example, those shown at B, will be cut by the line of force during its development.

This is the theory of Mutual Induction upon which the transformer is built, and we shall show in the following paragraphs how this theory is put into practice and discuss some of the effects produced.

960. In paragraph 955 we pointed out that when the current in the primary conductor is switched on, an E.M.F. is induced in the secondary conductor. A little consideration will show us that in this case **the E.M.F. is only momentary,** for it only lasts while the lines of force are cutting the conductor, that is to say, while the magnetic field is being formed. Therefore, if the current in the primary be maintained, no further effect will be produced in the secondary beyond the first voltage kick.

961. If, however, the current flowing in the primary be increased, then an additional number of magnetic

lines will shoot out round the conductor, and therefore another voltage kick will be induced in the secondary.

962. Similarly, if the current in the primary be reduced or switched off, the lines of force will collapse and converge on the primary conductor (*vide* paragraph 954), with the result that they again cut the secondary conductor, but this time **in the opposite direction.** Therefore a voltage kick will again be induced in the secondary conductor, but in this case tending to cause a current to flow through it in the opposite direction.

963. From these experiments it is evident that an E.M.F. will only be induced in the secondary circuit **whenever there is a variation in the primary current** or, rather, **when there is a variation in the magnetic field induced by the primary current.**

964. In the case of an Induction Coil, which is only a special form of transformer, this variation is produced, as we showed in Part I., by rapidly making and breaking the primary circuit, which causes an impulsive current to flow in the primary which, as we showed, induces an impulsive E.M.F. in the secondary.

965. In the case of a transformer proper, the variation in the magnetic field is produced **by causing an alternating current to flow in the primary,** which induces an alternating E.M.F. in the secondary; which, if the secondary be connected to a circuit, will cause an alternating current to flow through the secondary circuit.

966. We have already explained that causing a conductor to cut magnetic lines of force is in reality the same thing as causing a difference in the number of lines of force threading the circuit of which that conductor forms a part.

When considering a dynamo, it was easier to take the

former point of view; when considering a transformer, however, it is easier to take the other point of view, namely, that **an E.M.F. is induced in a winding when there is a change in the number of magnetic lines threading that winding.**

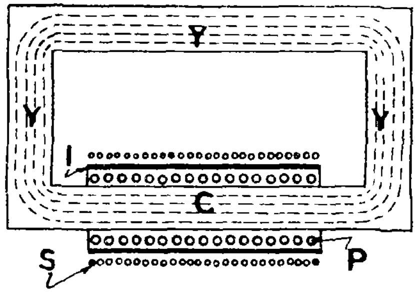


FIG. 210.

967. A transformer then consists of a Primary winding and a Secondary winding, wound close together but entirely insulated from one another. These windings surround an iron core made up of a large number of thin plates of iron, each plate being insulated from its neighbour by thin paper or varnish to stop eddy currents. An illustration of such a transformer is shown in section in Fig. 210, where P is

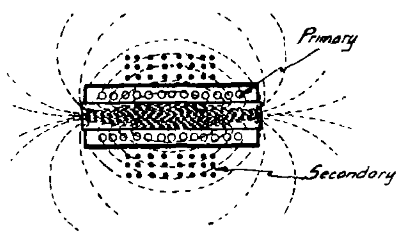


FIG. 211.

the primary winding, S the secondary winding, I the insulation between the primary and secondary windings, C the iron core which is yoked together by other pieces of iron YY, to form a return path for the magnetic lines of force (which are indicated by the dotted lines) of smaller reluctance than if the magnetic lines had to return through an air space. With such an arrangement practically all of the mag-

netic lines of force due to a current in one of the coils thread the other coil, whereas in the arrangement illustrated in Fig. 211 a large percentage of the lines of force induced by the primary current only thread some of the conductors of the windings.

Ratio of Transformers

968. In paragraph 877 we explained that the E.M.F. induced in a coil which is made to cut a given magnetic field at a given rate is greater in proportion to the number of conductors forming that coil.

969. If an alternating current is made to flow through the primary of a transformer, and if there is an equal number of turns in the primary and secondary, the E.M.F. induced across the secondary will be equal to that applied to the primary; but if the secondary has a greater or less number of turns than the primary the E.M.F. induced across the secondary will be greater or less in the same ratio.

970. Thus, if the primary consists of 100 turns and the secondary of 10,000 turns, and an alternating E.M.F. of 50 volts is applied to the primary, then an alternating E.M.F. of 5000 volts will be induced across the secondary and the ratio of the transformer is said to be 1-100, because the voltage across the secondary will be 100 times as great as the voltage applied to the primary.

971. At first sight it would appear that by this means we could get a very much greater power out of the secondary than is put into the primary because Watts = Volts × Amps, but a little consideration will show us that the current we can take out of the

secondary is decreased in proportion to the ratio by which the voltage is increased.

972. If we leave the transformer secondary winding disconnected from any outside circuit and apply an alternating E.M.F. to the primary, only a very small current will flow through the primary on account of the high inductance of the primary winding.

973. This may be regarded in another way; as soon as a current begins to flow through the primary, the lines of force induced by that current not only cut the conductors in the secondary coil, **but they also cut the conductors in the primary coil.** Obviously, therefore, a voltage is induced in the primary winding acting in an *opposite direction to the voltage applied to it* (*vide* paragraph 956). This opposite voltage is termed **the back E.M.F., due to inductance,** and its effect is to tend to prevent any current flowing through the primary, or, in other words, to choke back the current which would otherwise flow. It is for this reason that inductance coils, the use of which we shall describe later, are sometimes called "choking coils" or "chokes." The value of the current which will flow under these conditions is determined by the inductance of the winding, the value and frequency of the applied E.M.F., and the losses in the copper and iron. This current is called the magnetising current.

974. If now we take a certain amount of current out of the secondary by connecting the ends of the winding across a resistance, then it is evident that **this secondary current will also induce magnetic lines of force in the iron core in addition to those set up by the primary current,** because the secondary turns are also wound round the iron core. But the secondary current, as we

showed in paragraph 956, flows in the opposite direction to the primary current: therefore the lines of force induced by the current flowing in the secondary will have a neutralising effect on those induced by the primary current. The result on the primary is therefore to neutralise its effective inductance so that the back E.M.F. falls until a sufficiently **greater** magnetising current flows through the primary to make up for the neutralising effect of the secondary current. This reaction is instantaneous, so that in effect **the result of taking current out of the secondary is to cause a proportionate increase in the current taken by the primary.**

975. Now the number of lines of force induced in a given magnetic circuit is proportional to the product of the current and the number of turns. It follows, therefore, that if the secondary has 10,000 turns and the primary 100 turns, a current of one ampere flowing through the secondary will have the same magnetising effect as a current of 100 amperes in the primary. **From this it is evident that although the voltage across the secondary is increased in the proportion of the transformation ratio, the current which can be taken from the secondary will be decreased in the same proportion.**

Mechanical Analogy of a Transformer

976. Perhaps the best analogous example of the action of a transformer is the action of a mechanical gear box. In Fig. 212 a gear box is shown, consisting of a large gear wheel S in mesh with a small gear wheel P. If we take the twisting force or "torque" applied to the shaft as being analogous to the **Voltage** applied to a transformer (*vide* Part I. paragraph 54),

then the small gear wheel P can be taken to represent **the transformer primary,** and the larger gear wheel S to represent the **transformer secondary,** because any torque (which is analogous to voltage) applied to the shaft of this smaller wheel will cause a greater torque to be exerted by the shaft of the larger wheel S in proportion to the gear ratio.

977 Similarly, we can take the **speed of rotation** as

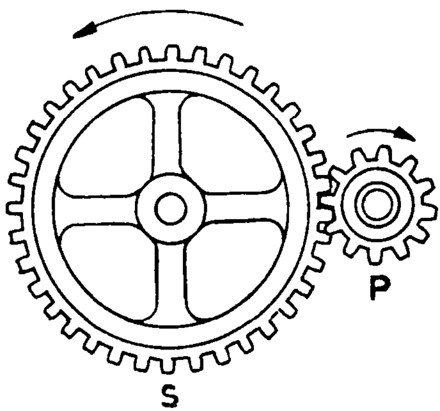


FIG. 212.

being analogous to the **current** flowing in the transformer windings (*vide* Part I. paragraph 51). Thus the speed of rotation of the smaller, or primary, wheel P will be greater than the speed of rotation of the larger wheel S in proportion to the gear ratio ; further, the direction of rotation in the larger wheel is opposite to the direction in which the smaller wheel rotates, just as the direction of the current in the secondary is opposite to the direction of the current in the primary of a transformer.

This analogy will be helpful later in studying the effect of using a transformer in the low frequency circuits of a wireless telegraph transmitter.

Inductance of Transformers

978. In explaining the effect of Mutual Inductance in coupled oscillatory circuits in Part I, paragraphs 372 to 387, we showed that when two inductance coils were brought so close together that all the lines of force induced by each coil threaded the other coil, the effective inductance of the two coils together was very much greater than the sum of their two separate inductances if the currents flowing through them were in the same direction, but that the effective inductance was zero if the currents flowing through them were in the opposite directions.

979. In the case of a transformer, the current in the two windings flows, as we have shown, in opposite directions; further, if the transformer is of the closed iron circuit type, as illustrated in Fig. 210, practically all of the magnetic lines induced by one coil thread the other; therefore, although both windings in themselves have a very high inductance, **the effective inductance of the transformer, as a whole, is practically zero.**

980. Obviously this only applies to a transformer in which all the magnetic lines induced thread both coils, but if any of the lines of force induced, say, by the primary do not thread the secondary coil, then the mutual inductance between the two coils is thereby reduced, with the result that the **effective inductance of the transformer, as a whole, is increased.** This factor can be

controlled to a great extent in the design of the transformer. *Magnetic lines of force will always take the path of least reluctance.* Now the reluctance of the path depends upon its length and the permeability of the material through which it passes. The permeability of iron is many hundreds of times greater than that of air, or other non-magnetic materials, so that where an iron path is provided for the magnetic lines of force, not only through the centre of the windings, *i.e.* through the core, but also from one end of the core to the other, as shown in Fig. 210; then provided the length of the iron path is not too great, practically all the lines of force pass round the iron, and therefore practically all thread both coils. Such a transformer is known as a closed iron circuit transformer.

981. If instead of providing a return path for the magnetic lines through an iron yoke we leave only the iron core of the coil, then the magnetic field induced by currents flowing round this core will be distributed in the surrounding air in much the same way as the field of a bar magnet is distributed, some lines of force being quite short, forming a path near the centre of the core, others traverse the whole core and form a path which embraces a large area round the core. Such conditions are illustrated in Fig. 211

982 From this illustration it will be seen that a large number of magnetic lines thread only part of the transformer windings, and this effect is known as magnetic leakage; the result is that the inductance of the transformer is very much increased

983. Inductance in the transformer, as we shall show later, is sometimes a useful quantity, so that **in some**

cases transformers are purposely made so as to have a large magnetic leakage, that is to say, so that a large number of the magnetic lines induced do not thread both coils. *Such transformers are known as open iron circuit transformers.*

PHASE RELATION BETWEEN CURRENT AND E.M.F. IN TUNED CIRCUITS

984. The phase relation between the current and the E.M.F. of an alternating current dynamo, when used to energise the condenser of an oscillatory circuit, has an important bearing on the action of a spark-gap. Therefore, before discussing the Transmitter as a whole, it is necessary that we have a clear idea of the phase relation of the current and E.M.F. in the charging circuit.

Meaning of Phase Difference

985. We have already shown that the variation of the E.M.F. generated by an alternator follows the sine law and that the current which will flow through a circuit when such an E.M.F. is applied to it will also follow the sine law.

986. The frequency of the alternating current, which flows as a result of the E.M.F., will be exactly the same as that of the E.M.F., but it does not follow that the E.M.F. will rise and fall **in unison** with the current; in other words, the E.M.F. will not necessarily be **in phase** with the current.

987. Since both the E.M.F. and the current vary with

relation to time, we may conveniently plot the E.M.F. curve on the same diagram as the current curve (*vide* paragraph 845), and since they both follow the sine law their relation with time may in both cases be represented by sine curves. To distinguish between the curve representing the E.M.F. and that representing the current, we shall in all diagrams represent **the current curve by a thick line** and the **E.M.F. by a thin line.** Also in all cases we will plot elapse of time or angle of displacement as abscissæ and the values of current and E.M.F. as ordinates.

988. If the E.M.F. generated by an alternator rises and falls in unison with the current which flows through a circuit as a result of this E.M.F., that is to say, if the current starts to rise at the same instant that the E.M.F. starts to rise and falls to zero again at the same instant that the E.M.F. falls to zero, then the E.M.F. and the current are said to be **in phase** with each other.

989. Under these conditions the curves representing the E.M.F. and the current will be as shown in Fig. 213, from which it will be seen that the points at which the current curve crosses the axis of time, *i.e.* the moments A, C, and E, coincide with the points at which the E.M.F. curve crosses the same axis. Further, it will be seen that the moments when the current reaches its maximum values at B and D coincide with the moments when the E.M.F. reaches its maximum values.

990. *If the E.M.F. generated by an alternator does* not rise and fall in unison with the current which flows through a circuit as a result of this E.M.F., then the E.M.F. and the current are said to be **out of phase** with each other.

991. Under these conditions the curves representing

the E.M.F. and the current may take different relative positions, depending upon the amount by which they are out of phase, an illustration of one of which is shown in Fig. 214, from which it will be seen that at the moments, A, C, and E, when the E.M.F. is zero, the current is at its maximum values, and at the moments, B and D, when the E.M.F. is at its maximum value, the current flowing in the circuit is zero.

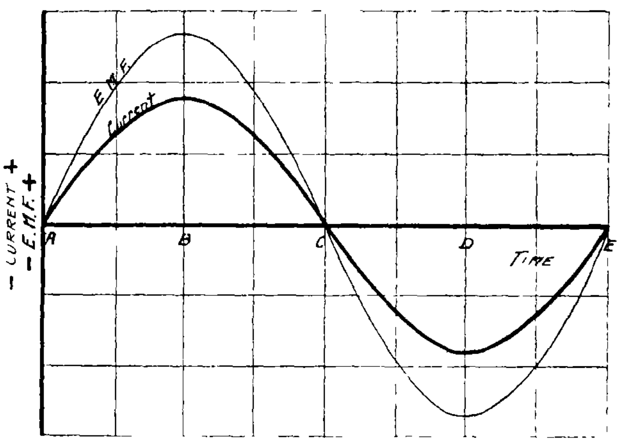


FIG. 213.

At first sight such conditions may appear impossible, but we shall show later how they can exist ; for the moment we only wish to explain what is meant by phase difference and how it can be defined

992. Every impulse or wave of E.M.F. applied to a circuit by an alternator will be accompanied by a corresponding wave of current flowing through that circuit, and therefore the current and the E.M.F. will have the same frequency, but there are a number of causes which

may prevent the current from reaching its maximum value at the same instant that the E.M.F. reaches its *maximum value. When the current reaches its maximum* value after the E.M.F., the current is said to **lag** behind the E.M.F., and when the current reaches its maximum before the E.M.F., as, for instance, in the case illustrated in Fig. 214, the current is said to **lead.**

993. In explaining the construction of a sine curve in

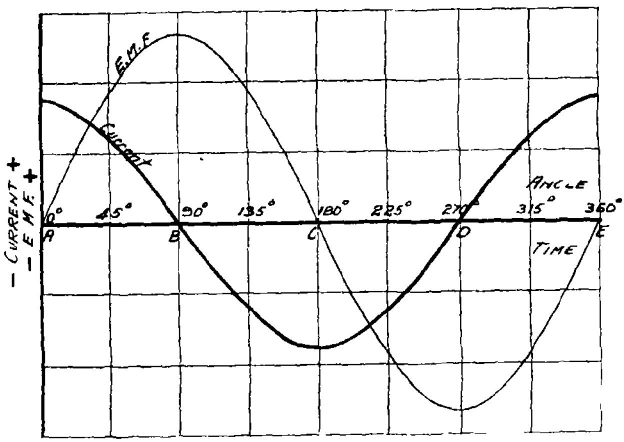


FIG. 214.

paragraphs 840 to 844, we showed how the length of time which elapses during one complete cycle can be expressed alternatively as an angle of 360°. In discussing the phase relation between alternating E.M.F.'s and currents, it is much more convenient to define this relation by the **difference in the angle** rather than by the difference in time between the moments when the two factors reach zero value. The reason for this is that the length of time taken for either the E.M.F. or

the current to pass through one complete cycle varies according to the frequency of the alternator, so that if we defined their phase relationship in terms of time, as, for example, by saying that the current reached its maximum value $\frac{1}{100}$ of a second later than the E.M.F., it would have a very different meaning for different frequencies of the alternations. On the other hand, if we define the phase relationship in terms of degrees, as, for example, by stating that the current in Fig. 214 reached its maximum value 90° earlier than the E.M.F., we should know that no matter what the frequency of the alternations, the current would be zero when the E.M.F. had reached its maximum, and that when the current had reached its maximum, the E.M.F. would have fallen to zero.

994. We may now proceed to discuss what conditions can exist in an electrical circuit to alter the phase relation between the current and the E.M.F. in that circuit, and then to show what is the phase relation between the E.M.F. and the current in the charging circuit of a Wireless Telegraph transmitter.

995. The explanation of these phenomena will be easier to follow by comparing them with analogous mechanical conditions, and in the following paragraphs a series of experiments are described illustrating by analogy the conditions which will produce a phase difference between the E.M.F. and Current in an electrical circuit.

Let us first enumerate the various factors in an electrical circuit and their analogous mechanical equivalents.

996. The three properties of an electrical circuit which we shall consider are its **Resistance, Inductance,** and

Capacity, and these we have frequently shown are analogous to three factors in any moving mechanical system, namely, *Friction, Mass,* and *Flexibility.*

997. In describing the **electrical property of inductance** in Part I. paragraph 67, we showed how it had an exactly similar effect as an **energy storing factor** in an electrical circuit to that possessed by *mass*, such as a flywheel in a mechanical system, and later, in paragraph 245, how the inductance of an oscillatory circuit had an exactly similar effect on **the natural frequency** of that circuit as mass had on the natural frequency of the vibratory mechanical system.

998. Also, when describing the **electrical property of capacity** (*vide* paragraph 72), we showed how its effect as an **energy storing factor** in an electrical circuit is similar to the effect of the flexibility of a spring in a mechanical system. We also showed later how the capacity of an oscillatory circuit had a similar effect on **the natural frequency** of that circuit as the flexibility of a steel spring had on the frequency of a vibratory mechanical system.

999. Again, the three factors operating in an electrical circuit, which we shall consider, are the **quantity,** the **current,** and the **E.M.F.,** and in Part I., paragraphs 50 to 54, we showed how these were analogous to three factors in any moving mechanical system, namely, **Movement, Speed,** and **Force.**

These analogous factors must be carefully borne in mind by the student to enable him to follow the deductions we shall draw from the experiments we are about to describe, and since all these experiments will be made with a rotary mechanical system, we can tabulate the mechanical factors with their electrical equivalents as follows :

1000. *Friction* in a mechanical system = **Resistance** in an electrical circuit.

Mass in a mechanical system = **Inductance** in an electrical circuit.

Flexibility in a mechanical system = **Capacity** in an electrical circuit.

Movement in a mechanical system = **Quantity** of Electricity in an electrical circuit.

Speed in a mechanical system = **Current** in an electrical circuit.

Twisting force or *Torque* in a mechanical system = **E.M.F.** in an electrical circuit.

1001. From this we can take certain units defining the value or magnitude of the factors operating in a mechanical system to represent the units defining the corresponding electrical factors. Thus:

Unit of Movement = 1 *revolution* and is analogous to **1 Coulomb.**

Unit of Speed = 1 *revolution per second* and is analogous to **1 Ampere.**

Unit of Torque = 1 *pound-inch*, and is analogous to **1 Volt.**

Effect of Resistance on Phase Relation

1002. *First Experiment.*—Take a rigid shaft with a means of applying a twisting force to it, and support it on a bearing in which it is free to rotate. Then this shaft can be taken to represent the conductors of an electrical circuit.

Fig. 215 illustrates this mechanical arrangement, and below is a diagram of the electrical circuit which it represents. The handle A in the mechanical system

represents the terminals " a " at the end of the conductor, and the twisting force which can be applied by pressure on the handle will be analogous to the E.M.F. applied by a battery or generator when connected to the terminals of the conductor.

1003. If we apply a twisting force, or, as it is usually called, a **Torque** to the shaft, we shall cause the shaft to

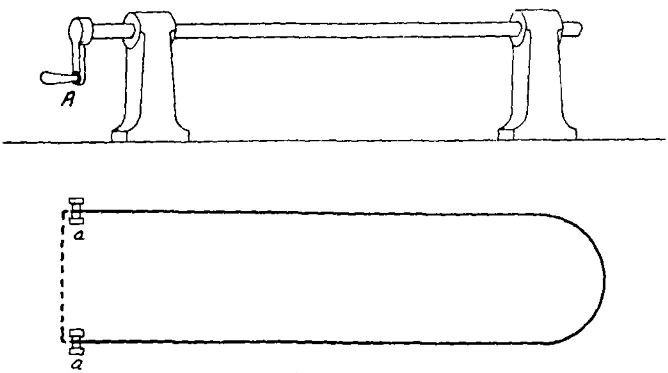


FIG. 215.

rotate in its bearings. If there were no friction either between the shaft and the bearing or between the shaft and the surrounding atmosphere, there would be no limit to the speed at which the shaft would rotate, or, in other words, it would rotate at an infinite speed, **no matter how small the torque applied to it**; but a certain amount of friction will always exist. The effect of this friction will be **to limit the speed** at which the shaft will rotate for a given torque applied to it, the limitation depending upon the amount of friction. Thus, instead of attaining an infinite speed, the shaft will rotate at a definite speed which, for a given frictional resistance,

will depend upon the torque applied. The greater the torque—the greater will be the speed.

1004. But another point to note is, that if the shaft has no weight in any of its moving parts, or, at all events, if its weight is negligible (such as would be the case if it were made out of a light aluminium tube) **it will attain its maximum speed the instant the torque is applied, and will moreover come to rest the instant the torque ceases.**

1005. Similarly, if we apply an E.M.F. to the terminals of the electrical circuit shown in Fig. 215, we shall cause a current of electricity to flow through that circuit, which, if the circuit had no resistance, would have an infinite value, no matter how small or how large the E.M.F. applied. But since every circuit will have a certain amount of resistance, the result is that only **a limited current will flow** through the circuit, its magnitude depending upon the E.M.F. applied and the resistance of the circuit, and, according to Ohm's law, is proportional to the E.M.F., and inversely proportional to the resistance. If, therefore, the conductor has a definite resistance, the current will rise to a certain value the instant the E.M.F. is applied, and will cease to flow the instant the E.M.F. ceases, also **the magnitude of the current will always be proportional to the magnitude of the applied E.M.F.**

1006. If instead of applying a uniform E.M.F. to the circuit as supplied by a battery, we apply an alternating E.M.F. (such as would be obtained from an alternator), it is evident that the current which will flow in the circuit, as the result of the applied alternating E.M.F., will vary in value exactly in phase with the E.M.F. applied, because if the magnitude of the current is always proportional to the magnitude of the E.M.F. the current

will always be zero when the E.M.F. is zero, and will attain its maximum value when the E.M.F. has attained its maximum. These results can be illustrated by a curve diagram, as shown in Fig. 216. The thin-line curve shows the variation of the E.M.F. applied to the circuit by an alternator, and the full-line curve re-

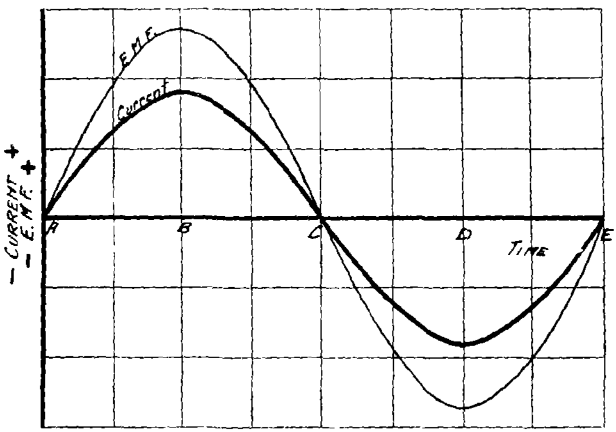


FIG. 216.

presents the current which will flow through the circuit possessing a certain resistance, as a result of this E.M.F.

EFFECT OF CAPACITY ON PHASE RELATION

1007. *Second Experiment.*—Let us now fix one end of a flat spiral spring to the far end of the shaft, and fix the other end of the spring to a suitable support, as shown in Fig. 217. This spring may be taken to represent a condenser connected in series with the conductor, and the whole mechanical system will therefore be analogous to the electrical circuit shown diagrammatically below.

1008. If we now apply a torque to the shaft through the handle, we will again cause it to rotate, but this time only **to a limited number of revolutions**, because as soon as the shaft begins to rotate, the spring will commence to exert an opposing torque to the shaft, and **the further the shaft rotates, the greater will be the opposing torque exerted by the spring.**

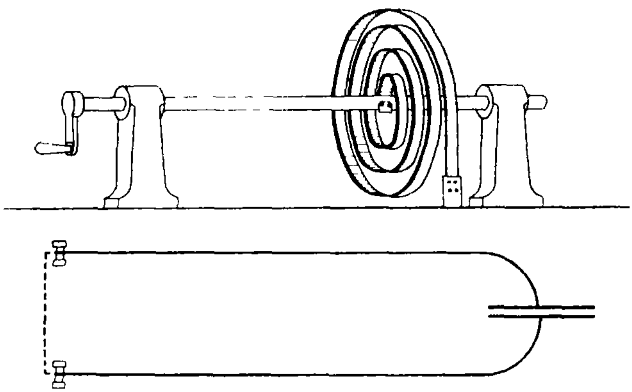


FIG. 217

1009. Obviously **a given** torque applied to the shaft will cause the shaft to rotate **until the opposing torque exerted by the spring is equal to it**, and the shaft will then come to rest.

1010. Similarly, if we apply a uniform E.M.F. to a condenser, we shall cause a current to flow through the conductors into the condenser. As the current begins to flow into the condenser, **the condenser begins to exert an opposing E.M.F.** (or, as it is usually called, a Back E.M.F.), with the result that the current will continue to flow only until the back E.M.F. of the condenser is equal to the E.M.F. applied to its terminals.

1011. Just as the number of revolutions that the shaft will rotate for a given torque will depend upon the flexibility of the spring to which the shaft is connected, so in the electrical circuit will the **quantity** of electricity which will flow through the conductors into the condenser for a given E.M.F. depend upon **the capacity of that condenser.** (*Vide* Part I. paragraph 31.)

1012. The important point to consider at the moment, however, is not the total quantity of electricity which flows into the condenser, but the relation as regards time between the flow of the current and the applied E.M.F., and also the relation between the applied E.M.F. and the back E.M.F. of the condenser.

1013. Referring to the first mechanical experiment described in paragraph 1003, we showed that, if there were no weight in any of the moving parts, any torque applied to the shaft will instantly cause it to rotate at a speed depending upon the magnitude of the applied torque, at which speed it will continue to rotate so long as the applied torque is maintained.

1014. Now the difference between these conditions and those of the experiment now under consideration is, that in the latter case **the effective torque is diminishing as the spring becomes compressed.**

1015. The effective torque is the difference between the torque applied to the shaft and the opposing torque exerted by the spring. If we take T to represent the effective torque, and T_a to represent the applied torque, and T_b to represent the opposing torque, then $T = T_a - T_b$.

1016. If, then, we apply to the shaft a torque which starts at zero and gradually increases at a uniform rate, **the speed of the shaft**, in this case, **will have a definite value depending upon the flexibility of the spring**

and *the rate of increase* **in the torque.** This can be better shown by taking a definite example. Let us suppose that the shaft is fitted with a handle 10 inches long; then it is evident that if a pressure of 1 lb. be applied to this handle, the torque applied to the shaft will be 10 inch-pounds, or if a pressure of 4 lbs. be applied to the handle, then the torque applied to the shaft will be 40 inch-pounds. Let us also suppose that the spring attached to the shaft is such that when the shaft has been rotated one complete revolution, it will exert a back torque of 10 inch-pounds, and likewise it will exert an additional 10 inch-pounds of back torque for every additional revolution of the shaft. Under such conditions it is evident that if a uniform torque of 10 inch-pounds is applied to a shaft it will rotate very rapidly for one complete revolution, and then come to rest.

1017. It is equally evident that if, instead of applying a uniform torque, we apply a torque which in one second grows from zero to 10 inch-pounds, the shaft will make one complete revolution during that time of one second; therefore its average speed during that time will be one revolution per second.

1018. Similarly, if we apply a torque which grows during one second from zero to 20 inch-pounds, the speed of the shaft in this case will be two revolutions per second. In both cases, however, **it will come to rest as soon as the applied torque stops increasing.**

1019. We may say then that (1) any rotation of the shaft requires **a change in the torque applied,** and (2) the speed of the shaft will be proportional to the **rate of increase** or the **rate of decrease** in the applied torque.

1020. Similarly, in an electrical circuit which

possesses capacity only, if a varying E.M.F. is applied to the circuit, a current will flow in the circuit. Further, **the magnitude of the current which flows will be proportional to the rate of change in the applied E.M.F.**, because for a definite capacity a given E.M.F. will only force a definite quantity of electricity into that condenser. For example: If during one second the E.M.F. gradually rises at a uniform rate from zero to one volt, and the condenser to which this increasing E.M.F. is applied has such a capacity that an E.M.F. of one volt applied to its terminals will force one coulomb of electricity into it, the average current during that second will be one coulomb per second, which is, in other words, a current of *one ampere.*

1021. Similarly, if in the example given above, the rate of increase in the applied E.M.F. were greater. For instance, if the voltage rose in half a second from 0-1 volt, thereby doubling the rate of increase, the current flowing into the condenser would also be doubled, for it would then be at the rate of two coulombs per second, which, in other words, is *two amperes.*

1022. These results can be conveniently illustrated by the curve diagram shown in Fig. 218, the thin-line curve representing the E.M.F. applied to the circuit, while the thick-line curve represents the current that will flow in the circuit as a result of this E.M.F.

It will be seen by following the thin-line curve that **the E.M.F.** starts from zero at A and rises at a uniform rate until the moment "B," after which time, until the moment "C," the E.M.F. remains at a constant value. At the moment "C" it starts to fall again at a uniform rate until once more it reaches zero at the moment "D." **The current** which is represented by the thick

line in Fig. 218, which flows as a result of this E.M.F., will therefore remain constant from A to B, because during that time the **rate of increase in the applied E.M.F. is constant,** and the current, as we have shown, is proportional **not** to the magnitude of the E.M.F., but to the *rate of change* in the E.M.F. From B to C no current will flow in the circuit, because during that time there is no variation in the applied E.M.F. From C to

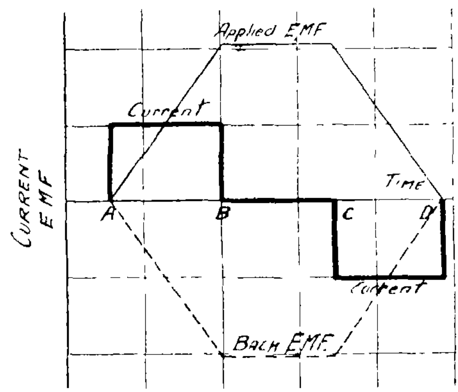


FIG. 218.

D a uniform current will again flow in the circuit, because during that time the E.M.F. is again varying at a uniform rate; but since the E.M.F. is then decreasing, the current will flow in the circuit in the opposite direction to what it did during the time A to B when the E.M.F. was increasing.

1023. We may say, then, that the current flowing into a condenser through a circuit which possesses no inductance, as a result of applying a varying E.M.F., **is proportional to the rate of change in the applied E.M.F.**

1024. If now we draw a curve, showing the variation of voltage generated by an alternator, as shown in Fig. 219, it will be seen that the rate of change in the voltage, as indicated by the steepness of the curve (*vide* paragraph 818), is greatest at the moments A, C, and E, *i.e.* at the moments when the voltage drops to zero, and also that the rate of change is zero when the voltage is at its maximum E.M.F., *i.e.* at the moments B and D, because at these instants the E.M.F. curve is practically

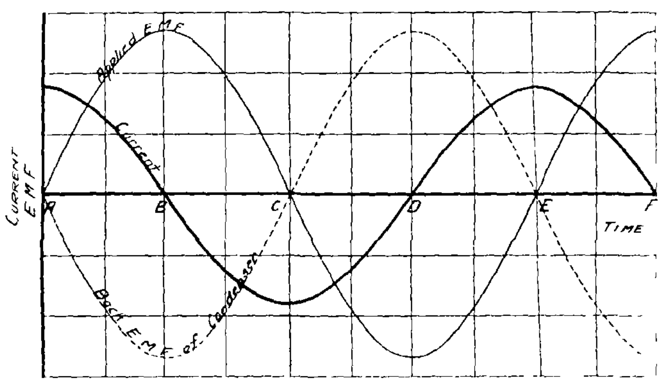


Fig. 219.

horizontal, indicating that there is practically no change in the E.M.F.

1025. It follows, then, that the current flowing into the condenser **will be at its maximum value when the applied E.M.F. is zero,** and, further, that the current will be zero when the applied E.M.F. is at its maximum value. The thick-line curve in Fig. 219, therefore, will represent the variation of the current flowing into the condenser, as a result of applying an alternating E.M.F. to that condenser.

1026. From a study of this diagram it will be seen that the current reaches its maximum value 90° before the E.M.F. We may say, then, that *when an alternating E.M.F. is applied to a circuit possessing capacity, but neither resistance nor inductance, the current flowing in that circuit will* **lead** *by* 90°.

1027. It is evident that the **back E.M.F.** of the condenser will be greatest when the greatest quantity of electricity has flowed into it, just as the greatest opposing torque exerted by the spring in the second experiment just described will be greatest when the shaft has been rotated the greatest number of revolutions in a certain direction (*vide* paragraph 1008). It is obvious, therefore, that **the back E.M.F. of the condenser will always reach its maximum value when the current has flowed into the condenser for the greatest length of time in one direction.**

1028. Referring to the current curve shown in Fig. 219, it is evident that the current has flowed for the greatest length of time in one direction at the moments B, D, and F. It follows, therefore, that the back E.M.F. of the condenser will reach its maximum value at these moments. And since the back E.M.F. must in such a case be opposed to the applied E.M.F., the curve of the back E.M.F. will take the position shown by the dotted-line curve in Fig. 219.

Effect of Inductance on Phase Relation

1029. *Third Experiment.*—Let us now fix on to the shaft a large flywheel, instead of a spring, in such a way that it will revolve with the shaft, as shown in Fig. 220.

This flywheel may be taken to represent an inductance mounted in series with the conductor, and the

whole mechanical system will therefore be analogous to the electrical circuit shown diagramatically in the same figure. If we apply a uniform torque to the shaft, it will, **owing to the inertia of the flywheel, only gradually get up speed.** Further, the speed will continue to increase so long as the torque is maintained. It is evident, therefore, in such a case that the speed at which the flywheel will rotate at any moment after a given

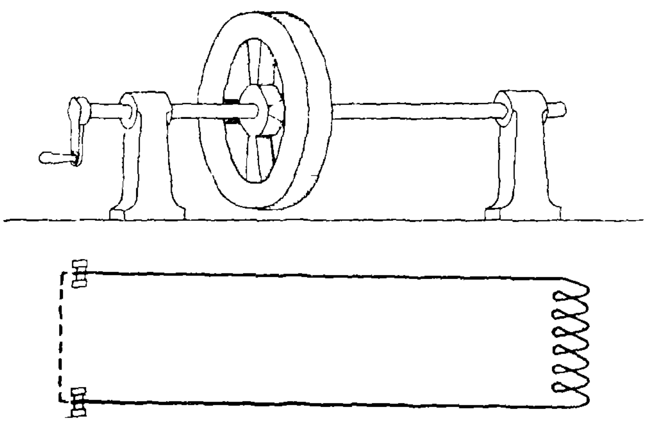


FIG. 220.

torque is applied **will depend upon the length of time during which that torque is applied.**

1030. If we repeat this experiment, but applying a much greater torque to the shaft, it will be found that although the shaft will gradually increase in speed as before so long as the torque is maintained, that its **rate of increase** is greater than in the first case—in fact, it will be found that **the rate of increase in the speed** of the shaft on which is mounted a certain sized flywheel **will be proportional to the magnitude of torque applied.**

1031. Similarly, when a uniform E.M.F. is applied to a circuit, which possesses inductance only, the current will start at zero and gradually increase as long as the E.M.F. is maintained, and for a given inductance **the rate of increase in the current will be proportional to the magnitude of the E.M.F. applied.** We may therefore conveniently represent these results by curves, as shown in Fig. 221, the thin-line curves illustrating the applied E.M.F., and the thick-line curves the current which flows as a result of the applied E.M.F. in the circuit.

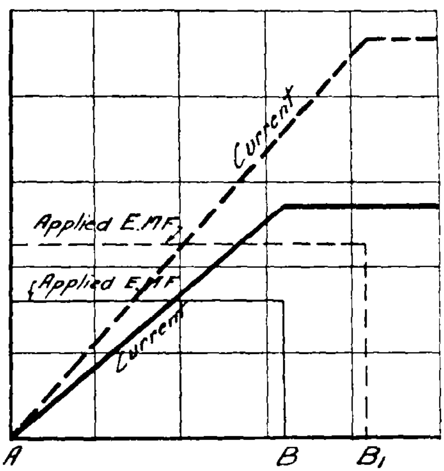


FIG. 221.

1032. It will also be found that for a given applied E.M.F. the rate of increase in current will depend upon the inductance of the circuit, just as in the mechanical experiment the rate of increase in the speed of the shaft for a given torque applied will depend upon the size of the flywheel.

1033. Now if, after applying a torque to the shaft for a certain length of time, during which time the flywheel has attained a certain speed, the torque be reduced to zero, the shaft, owing to the momentum of the flywheel, will continue rotating at this speed for ever, assuming that there is no friction to bring it to rest.

1034. Similarly, in the analogous electrical circuit, if an E.M.F. be applied for a certain length of time, during which time the current has attained a certain value, this current would continue to flow in the circuit for ever if the E.M.F. were suddenly reduced to zero, assuming that there were no resistance in the circuit. These results are also illustrated in Fig. 221, where, at the moment " B " or B_1, the E.M.F. drops to zero and the current curve then becomes horizontal.

1035. Let us now, instead of applying a uniform torque to the shaft, apply one which starts at zero, gradually increases to a maximum value at the moment " B," and then gradually drops again at a uniform rate to zero at the moment " C," and note what will be the logical effect of this applied torque on the speed.

We may illustrate this torque by a sine curve, as shown by the thin line in Fig. 222, in which the abscissae represent the duration of time and the ordinates represent the value of the applied torque.

1036. In the foregoing experiment we showed that for a given sized flywheel *the rate of increase in the speed* of the shaft depends upon *the magnitude of the torque,* and, further, that *the magnitude of the speed* of the shaft at any moment depends upon the *length of time during which the torque has been applied.* It follows from this that in the case now under consideration, (1) **the speed of the shaft will start at zero and will gradually increase to a maximum value,** (2) **the rate of increase in its speed will be greatest when the applied torque is at its maximum,** and (3) **its speed will be greatest when the applied torque has been maintained for the greatest length of time,** *i.e.* when it has dropped to zero at the moment " C."

1037. If, then, we plot another curve, taking the ordinates to represent *the speed of the shaft and the* abscissae to represent duration of time, the curve illustrating the speed of the shaft under these conditions will have the following characteristics :

(1) The curve will start at zero at the moment when the torque is applied, *and will gradually increase to a* maximum value.

(2) The steepness of the curve (which indicates the rate of increase in the speed) will be *greatest when the applied torque* is at its maximum.

(3) The height of the curve (which indicates *the magnitude* of the speed) will be greatest when the applied torque has been maintained *for the greatest length of time.*

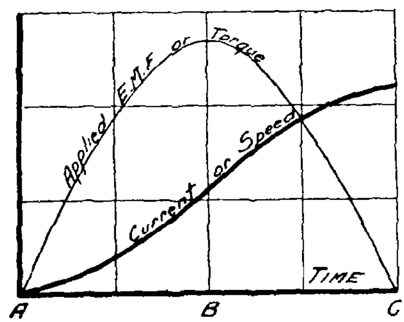


FIG. 222.

1038. Such a curve is shown by the thick line in Fig. 222, which starts from zero with a gentle slope, but with its slope increasing in steepness until it is steepest at the moment " B," when the applied torque is at its maximum, *after which time the slope of the curve will get* gradually less until it attains its maximum height at the point " C," when the torque has been applied for the greatest length of time.

1039. Similarly, with an electrical circuit which possesses *inductance only, if the E.M.F. is applied in* such a way that it starts at zero, gradually increases to a

maximum, and then gradually drops to zero again, the current flowing in the circuit, as a result of this E.M.F., will increase to a certain maximum value depending upon the inductance of the circuit, the average value of the E.M.F. applied, and the length of time for which it is applied ; **the rate of increase in the current will be greatest when the E.M.F. is at its maximum** and the **greatest current will flow when the E.M.F. has been applied for the greatest length of time.** Thus the curves, as shown in Fig. 222, may also be taken to represent the results obtained in an electrical circuit, under the conditions just described, the torque curve representing the applied E.M.F. and the speed curve the current flowing as a result of this E.M.F.

1040. Let us now repeat this experiment, and at the moment "C," when the torque applied to the shaft has dropped to zero, start applying a similar torque in the opposite direction, which grows at the same rate as before to a maximum value at the moment "D" then drops to zero again at the moment "E" (Fig. 223).

We will assume that the time occupied by this reversing process, namely, the time CE, is equal to the time occupied by the first process, namely, the time AC.

1041. At the moment "C," when the torque has dropped to zero, the shaft is revolving at its maximum speed, so that on account of the momentum of the fly-wheel the effect of applying a torque in the reverse direction will not be to reverse the direction of rotation of the shaft, but merely **to slow up the shaft** ; in this case the rate of the decrease in speed will depend upon the magnitude of the opposing torque, therefore the **rate of decrease** in the speed will be slight at first when the opposing torque starts to grow, until at the moment

"D," when the opposing torque is at its maximum, the rate of decrease in the speed of the flywheel will be greatest, and it will come to rest at the moment "E," when the reversed torque has been applied for the same length of time as before.

1042. If this process of applying a gradually increasing and decreasing torque first in one direction and

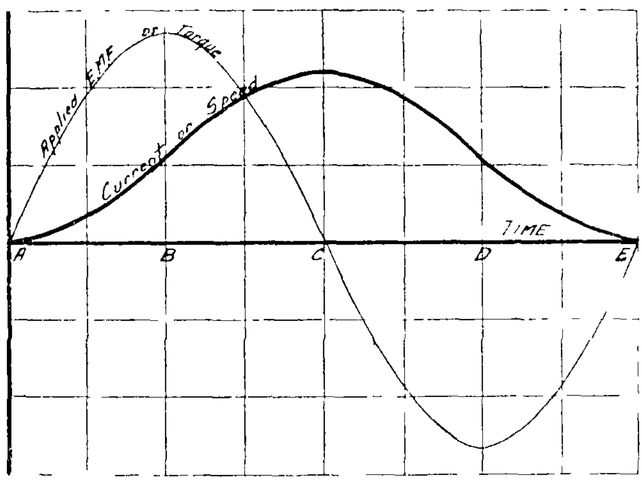


FIG. 223.

then in the other be repeated at regular intervals, the same sequence of events as those described between the moments "A" and "E" will be repeated indefinitely. Examining this curve, it will be seen that, as already pointed out, the rate of increase in the speed (as indicated by the steepness in the slope of the speed curve) will always be greatest when the applied torque (as indicated by the height of the torque curve) is at its maximum; and, further, that the speed attained by the

shaft will be at its maximum in each case (as indicated by the height of the speed curve) when the torque has been applied for the greatest length of time in one direction, which, in each case, coincides with the moment when it has dropped to zero.

1043. A further point to notice is that the speed always attains its maximum value one-quarter of a complete period, or 90° later than the moment at which the torque has reached its maximum value. *We may say, therefore, that the speed of the shaft* **lags** *behind the torque applied to it by* 90°, this lag being due to the effect of the momentum of the flywheel.

1044. For similar reasons in an electrical circuit which possesses inductance only, if an alternating E.M.F. be applied to the circuit, the phase relation between the applied E.M.F. and the growth of the current which flows in the circuit as a result of this applied E.M.F. will be exactly the same as the phase relation between the applied torque and the resulting rotation of the shaft in the experiment just described, and the curves illustrated in Figs. 222 and 223 may also be taken to represent the applied E.M.F. and the resulting current. Thus it will be seen that *if a circuit possesses inductance only, the current flowing through the circuit as a result of applying an alternating E.M.F. will be a unidirectional current which rises and falls 90° later than the applied E.M.F.*

1045. This, however, only occurs exactly if there is no resistance in the circuit—conditions which can never exist in practice. The effect of any resistance in the circuit will be to reduce the maximum value to which the current grows in the first half-period of applied E.M.F., and to increase the rate at which it falls in the second

half-period, **with the result that the current reaches zero value before the opposing E.M.F. has reached zero,** so that the current will then start to grow in the opposite direction until the E.M.F. has reached zero. No matter how small the resistance, this effect will increase during each half-period **until the current rises to an equal value in both a positive and negative direction,** when the current then takes a steady phase relation with the E.M.F., as shown in Fig. 224. If the resistance is very small compared with the inductance, the current will lag very nearly 90° behind the E.M.F., but will take a

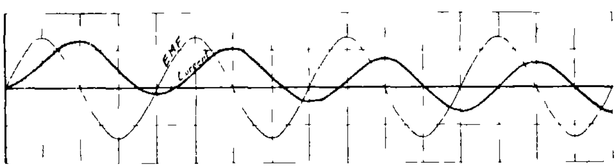


FIG. 224.

considerable number of periods to settle down to its steady condition.

1046. In the circuits we are leading up to, namely, the conditions obtained in the low-frequency circuits of a transmitter, this effect of the resistance is not important, provided the resistance of the circuit be kept reasonably low.

Effect of Resonance on Phase Relation

1047. *Fourth Experiment.*—Having noted the effect which capacity and inductance in a circuit have separately on the phase relation between the E.M.F. and the Current which will flow as a result of that E.M.F., we are now in a position to analyse the results which will be

obtained when an alternating E.M.F. is applied to a circuit possessing **both capacity and inductance.**

1048. Such a circuit would be analogous to a mechanical system similar to that shown in Fig. 225, which consists of a shaft on which is mounted a flywheel, and to which also is attached one end of a spring, the other end of the spring being fixed rigidly to some immovable *object as before.*

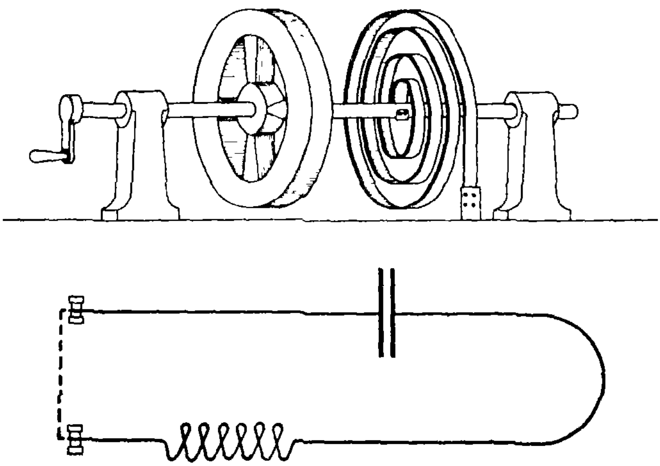


FIG. 225.

1049. If we apply a uniform torque to this shaft, we shall again cause it to rotate. In this case, **owing to the *action of the spring*,** *as soon as the shaft commences to* rotate the spring will commence to exert an opposing torque, with the result that although the applied torque be maintained at a uniform value, the effective torque will be reduced in proportion to the amount the shaft rotates. The further the shaft rotates, the greater will

be the opposing torque exerted by the spring, and therefore the less will be the effective torque.

1050. Again, **owing to the inertia of the flywheel** mounted on the shaft, the speed at which it will rotate only gradually increases, and will be greatest when a torque has been applied in one direction the greatest length of time (*vide* paragraph 1036); it follows that **the speed of the shaft will be greatest** at the moment when the opposing torque exerted by the spring is equal to the torque applied to the shaft, that is to say, **when the effective torque becomes zero,** because up to this moment the effective torque will have been tending to rotate the shaft in the direction in which it started.

1051. Again, since the applied torque is maintained at a uniform value, and the back torque exerted by the spring is gradually increasing as the shaft rotates, it also follows that the **rate of increase** in the speed of the shaft, on account of the effect of the flywheel, will be greatest when the torque is first applied, for at this moment the **effective** torque is at its greatest value; and we have shown in paragraph 1036 that the rate of increase in the speed is proportional to the magnitude of the torque.

1052. If, therefore, we draw a curve illustrating the growth in the speed of the shaft under these conditions, for a uniform applied torque, this curve will start from zero with a steep slope, and although continually increasing in height, the steepness of the slope will get less and less as the effective torque diminishes.

1053. Again, **the back torque** exerted by the spring is proportional to the number of times the shaft has rotated, and therefore it is evident that the **rate at which this back torque increases** will be greatest when the speed of the shaft is greatest; therefore the curve

representing the growth of the back torque under these conditions will start at zero with a gentle slope and gradually get steeper and steeper as the speed of the shaft increases, because the steepness of this curve represents the **rate of increase** in the back torque.

1054. If, therefore, we draw a set of curves to illustrate the results obtained from the above experiment up to the point where the back torque exerted by the spring is equal to the applied torque, they will take the form shown in Fig. 226, the thin-line curve representing the applied torque, which is maintained at a uniform value ; the thick-line curve representing the speed at which the shaft rotates, which will start at zero and increase rapidly first and then more slowly until the moment B, when the effective torque is zero ; and the dotted-line curve represents the growth of the back torque exerted by the spring.

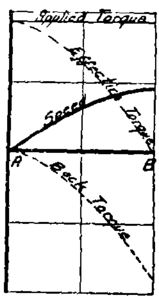


FIG. 226.

The effective torque will at any moment, of course, be the difference between the applied torque and the back torque.

1055. So far, we have only considered what takes place up to the moment when the back torque of the spring is equal to the applied torque, that is to say, up to the moment B in Fig. 226.

1056. Now we have *shown that at this moment*, although the effective torque is zero, **the shaft is revolving at a definite speed,** and therefore if the effective torque remained at zero, the shaft, owing to the momentum of the flywheel, would continue to revolve at this speed indefinitely (*vide* paragraph 1033). Since, however,

every part of a revolution which it makes will continue to increase the back torque exerted by the spring, it is evident that after the moment B, even though the applied torque be maintained at a positive value, **the effective torque becomes a negative value,** that is to say, instead of assisting the rotation of the shaft, it will oppose it.

1057. It follows, therefore, that after the moment B the shaft, instead of continuing to revolve at a uniform rate, will slow up, although for some time it will continue to revolve. Now **the rate at which it slows up** will depend upon the magnitude of the opposing torque (*vide* paragraph 1041), and since the magnitude of the opposing torque starts at a very small value and gradually increases, it follows that the shaft slows up very slowly at first and then more rapidly as the opposing torque increases, until it finally comes to rest.

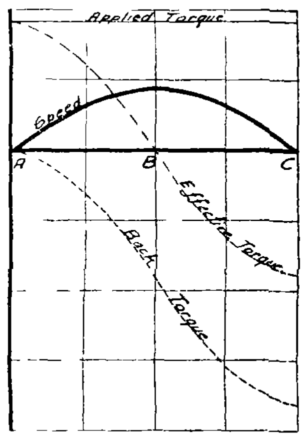


FIG. 227

1058. We may, then, continue our speed curve after the moment B, as shown in Fig. 227, where it will be seen that at the moment B it is practically level and gets steeper and steeper in a downward direction, until at the moment C it reaches zero, when the shaft has come to rest.

1059. The back torque exerted by the spring will, as we have already explained, increase so long as the shaft is rotating in the same direction; therefore it will continue to increase right up to the moment C. Its

rate of increase, however, will be greatest when the shaft is rotating at its maximum speed, that is to say, at the moment B, and its rate of increase will get less and less, and will be least when the shaft has come to rest, that is to say, at the moment C. We may therefore continue the curve representing the increase in the back torque of the spring, as shown by the dotted line in Fig. 227, which is steepest at the moment B and almost level at the moment C.

1060. Similarly, the curve representing the effective torque can be continued by subtracting the back torque of the spring from the applied torque as before.

1061. On account of the fact that **the back torque at the moment C is greater than the applied torque,** and that the shaft at that moment has come to rest, it is evident that the shaft will at this moment commence to rotate in the opposite direction. No object, however, will be gained for the purpose of this explanation by noting the results which would be obtained beyond the point C.

1062. There is one very important point to note here, namely, **the length of time taken by the shaft to get up speed and finally come to rest, that is, from the Moment A to the Moment C, is entirely independent of the magnitude of the torque applied to the shaft.** Thus if in the experiments just described the applied torque were doubled, the length of this time period would remain unaltered ; because, although double the number of revolutions would have to be made by the shaft before the back torque of the spring equalled the applied torque, the average speed of the shaft would also be doubled. It should be noted also that the average rate of increase will be doubled. **The length of time taken depends entirely upon the mass of the flywheel**

and the flexibility of the spring. The bigger the flywheel and the more flexible the spring, the greater the interval of time between the moment the shaft starts to rotate to the moment it comes to rest; and, *vice versa*, the smaller the flywheel and the stiffer the spring, the shorter the interval of time.

1063. This interval of time is known as the **natural time period,** or, more strictly speaking, half the natural time period of the system, and plays a most important part, as we shall show in the next experiment when a periodically varying torque is applied to the shaft.

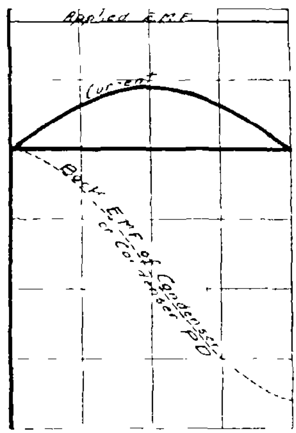


FIG. 228.

1064. Exactly similar results to this will be obtained if a uniform E.M.F. be applied to a circuit possessing both inductance and capacity. In such a case the current will start growing rapidly at first, then more and more slowly until it reaches its maximum value, when the back E.M.F. of the condenser is equal to the applied E.M.F. After this moment the current will fall slowly at first and then more and more rapidly, until it falls to zero, **while the back E.M.F. of the condenser continues to rise so long as the current is flowing into it.** In Fig. 228 the curves are drawn representing the applied E.M.F., the current which flows as a result of this E.M.F., and the back E.M.F. of the condenser, or, as it is usually called, the "Condenser P.D.," to distinguish it from the applied E.M.F.

1065. Further, it will be found that **with every circuit there is a definite length of time taken for the current to grow to a maximum value and then fall to zero. This is known as the natural time period of the circuit,** which is entirely independent of the E.M.F. applied to it, and depends solely upon the inductance and capacity of the circuit.

1066. Now apart from the rate of growth of the condenser P.D., one interesting and very important difference will be noticed between these results and those obtained when a condenser is charged through a circuit possessing no inductance. In the latter case, as shown in the second experiment described in paragraph 1022, the condenser is only charged to an E.M.F. **equal** to the applied E.M.F., whereas in the case just described the condenser is charged to an E.M.F. exactly **double** the applied E.M.F. This at first sight seems curious, but is quite simply explained if looked at from the energy-storing point of view.

1067. When we cause a flywheel to rotate by applying a torque to the shaft, we are storing energy in the flywheel so long as we are increasing its speed. Thus a flywheel rotating at a certain speed represents so much energy stored, but when we take energy out of the flywheel we decrease its speed.

Evidently, therefore, if no energy is taken out of the flywheel and no more energy is put into it, it will go on rotating for ever at a uniform speed, as observed in the experiment described in paragraph 1033.

On the other hand, when we compress a spring, as, for instance, by rotating the shaft to which the centre is attached, we are storing energy into the spring so long as we are compressing it, that is to say, in this case so long as we are rotating the shaft. But when we take

energy out of the spring, we decrease the extent to which it is compressed, that is to say, in this case we rotate the shaft in the other direction.

1068. In the experiment just described, when we applied a uniform torque to a shaft on which are mounted both a flywheel and a spring, we are up to the moment B, Fig. 227, storing energy both in the spring and in the flywheel, because we are increasing the speed of the flywheel and we are compressing the spring by rotating the shaft to which it is attached. After the moment B, however, we are no longer increasing the speed of the flywheel, but **decreasing** it; therefore the energy, which was stored in it up to the moment B, is being taken out of the flywheel, and this energy is being taken up in the spring, because since the shaft continues to rotate, the spring is still storing energy; thus it will be seen that at the moment C in the experiment just described there is no energy in the flywheel, because it is at rest and all the energy is in the spring, which is then compressed to a maximum amount.

1069. Similarly, in an electrical circuit which contains both inductance and capacity, when a uniform E.M.F. is applied to the circuit, energy is stored at first both in the inductance and in the condenser, due to the fact that the current in the inductance is increasing, and to the fact that the condenser voltage is increasing. After a certain length of time when the condenser E.M.F. is equal to the applied E.M.F., the current flowing through the circuit, and therefore through the inductance, decreases and therefore the inductance is giving up its energy. This energy is stored up in the condenser, thus still further increasing the P.D. to which the condenser is charged.

1070. Let us now go one step further with the mechanical experiment described in paragraphs 1047 to 1061 and study what will be the effect if, at the moment C in Fig. 227, we suddenly reverse the direction of the applied torque, as shown by the continuation of the applied torque curve in Fig. 229.

1071. At this moment C the shaft and, therefore, also the flywheel is at rest, so that the conditions, so far as the rotation of the shaft is concerned, are exactly similar to those at the moment A. If, therefore, **the effective torque** were of the same value at the moment C as at the moment A, but in the opposite direction, then the shaft would obviously commence to rotate in the opposite direction, and its rate of acceleration would follow exactly the same cycle as it did between the moments A and C, and the shaft would once more come to rest at the moment E, taking exactly the same length of *time as it did to come to rest at the moment C, that is* to say, the length of time AC would be exactly the same as the length of time CE.

1072. But at the moment C the **effective torque** is not only in the reverse direction, but is greater than it was at the moment A, because at the moment C, when the applied torque has been reversed, **it is acting in the same direction as the back torque of the spring,** so that the effective torque at this moment is the applied torque plus the back torque of the spring.

1073. The effect, therefore, would be to increase the speed of the shaft at a very much greater rate than before, although, for reasons already explained (*vide* paragraph 1062), it will come to rest in exactly the same length of time as before, namely, at the moment E. It is evident, therefore, that **the maximum speed which it attains**

at the moment D will be very much greater than it was at the moment B. We may therefore continue the

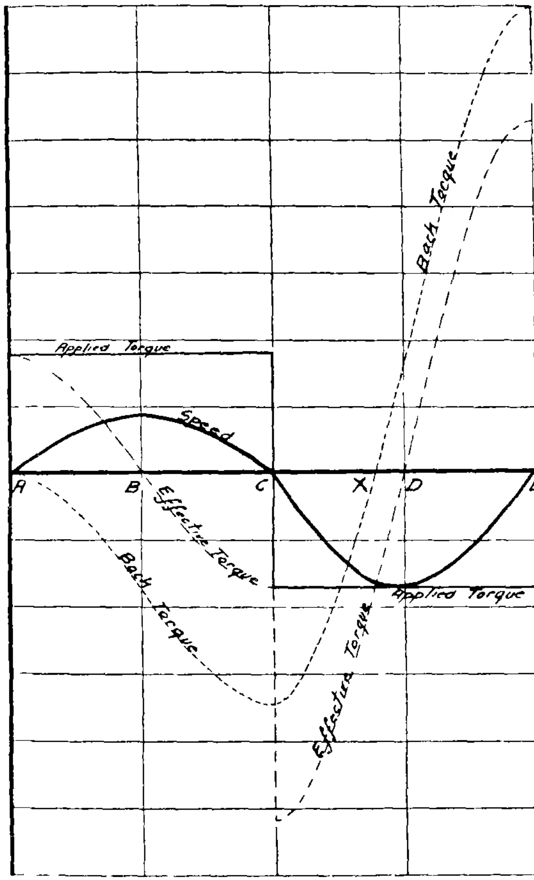


FIG. 229.

speed curve as shown in Fig. 229, the maximum height to which this curve rises being greater at the moment

D than at the moment B. In other words, the speed curve will have a greater amplitude in the second half-period than in the first half-period.

1074. Now up to the moment C, while the shaft was rotating in a "positive" direction, the back torque exerted by the spring increased so long as the shaft was rotating. After the moment C, however, the shaft, as we have shown, rotates in the opposite direction. It is evident, therefore, that after the moment C the back torque exerted by the spring will decrease. For reasons already explained, its rate of decrease will be greatest when the speed of the shaft is greatest, *i.e.* at the moment D; therefore at this moment the back torque curve will be steepest. Owing to the very much greater speed at which the shaft rotates during this second half-period, it will be found that in rather less than half the period of time CE, that is to say, during the time CX, the shaft has rotated the same number of revolutions that it did during the whole of the period AB, so that at the moment X it will have returned to its original normal position. At this moment, therefore, the back torque exerted by the spring will be zero, as illustrated by the back torque curve. After the moment X, on account of the fact that the shaft is still rotating in the same direction, the back torque will rise until it reaches its maximum value at the moment E. This maximum value will, however, be very much greater than that attained at the moment C at the end of the first half-period, because on account of the higher speed at which the shaft rotates during the second half-period, the number of revolutions it makes during the time XE will be far greater than the total number of revolutions it made during the whole of the time AC.

1075. For reasons already described, therefore, the back torque exerted by the spring will rapidly fall to zero at the moment X, and will then rapidly increase in value until it attains its maximum value at the moment E. This maximum value, however, at the moment E will be twice as great as it was at the moment C and four times as great as the applied torque.

1076. Looking at this experiment from the energy storing point of view, it will be seen that between the moments C and D not only is the energy which was stored in the spring at the moment C being transmitted back to the flywheel, but also the flywheel is storing a further amount of energy from the force applied to the shaft. At the moment D, therefore, the flywheel will have stored all the energy it had at the moment B, plus the amount of energy which is being given to it between the moments C and D. After the moment D, however, it commences to give its energy back to the spring till at the moment E the spring has stored all the energy applied to the system between the moments A and E.

1077. Now exactly similar results will be obtained in an electrical circuit possessing inductance and capacity only if at the moment when the current falls to zero, as described in paragraph 1064, the E.M.F. applied to the circuit be reversed. Therefore the curves in Fig. 229, illustrating applied torque, speed and back torque, will equally represent the equivalent electrical factors of **applied E.M.F., current,** and **condenser P.D.** To avoid confusion, we have redrawn these curves in Fig. 230 to represent the electrical properties.

1078. Now bearing in mind the fact explained in paragraph 1065, that the magnitude of the applied E.M.F. makes no difference to the interval of time taken by the

current to grow to the maximum value and fall to zero, and that it only alters the maximum value which that current attains during that half-period, it is evident that if, instead of applying a uniform E.M.F. to the circuit during the time AC, we applied an alternating E.M.F. which starts at zero, gradually rises to a maximum value and then falls again to zero, that the resulting current will again gradually rise to a certain maximum value and then fall to zero in exactly the same length of time as before. If then we draw curves showing such an applied alternating E.M.F., and showing the resulting current which will flow in the circuit, they will take the *form shown in Fig.* 231, the *thin-line curve* representing the applied E.M.F., and the thick-line curve representing the current for one half cycle only.

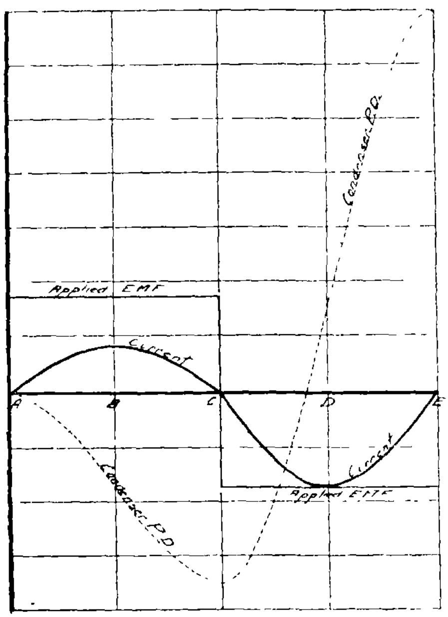


FIG. 230.

1079. In previous paragraphs we showed that when a uniform E.M.F. is applied to the circuit, the condenser P.D. reaches a value exactly double that of the applied

E.M.F. This, however, is not exactly the case when a varying E.M.F. is applied. It can be shown that when an alternating E.M.F. is applied to the circuit having the same time period as that of the circuit, that **in the first half-period** the condenser P.D. will reach a value $\frac{\pi}{2}$ times the **maximum** value of the applied E.M.F., or about 2·3 times the **effective** or R.M.S. value of the applied E.M.F. (*vide* paragraph 913).

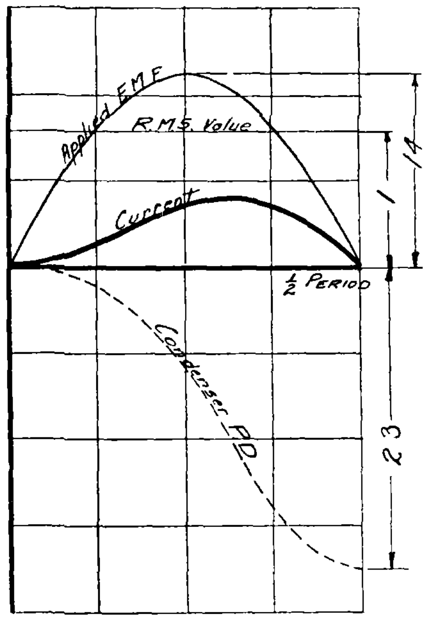


Fig. 231.

1080. In the various diagrams up to the present we have illustrated the condenser P.D. curve. In most resonance diagrams, however, it is usual to show the curve of the P.D. at the terminals of the generator (assuming that all the inductance is in the generator) which is connected across the condenser. The generator or transformer P.D. is always exactly equal, but opposite in sense, to the condenser P.D., and can therefore be plotted on the opposite side of the axis, as shown in Fig. 232, thus making a more convenient diagram

to refer to. This plan will be adopted in all future diagrams.

It is evident that if we continue this experiment by applying at the moment C an E.M.F. in the opposite direction, which again starts at zero, grows to a maximum value, and drops to zero in the same length of time, the curve illustrating the current and the generator P.D. will follow a similar sequence to those illustrated in Fig. 232, the only difference being in the magnitude of the different factors. In other words, the transformer P.D. and the current will rise to a greater and greater maximum value with each succeeding half-period (as illustrated in Fig. 233), but they will always bear the same phase relation to the applied E.M.F. as during the first half-period.

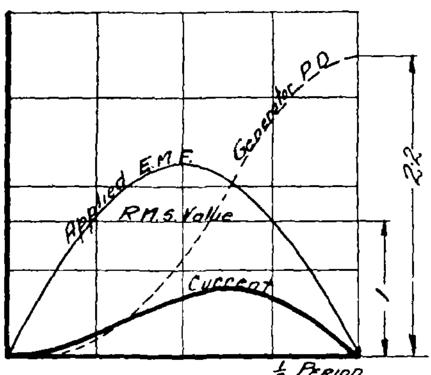


FIG. 232.

1081. During this second half-period and all succeeding half-periods the current and condenser P.D. curves will be symmetrical, because at the moment 1, 2, 3, etc., the condenser P.D. instead of starting at zero, as was the case at the moment O, starts at approximately its maximum value, while the applied E.M.F. at these moments is zero. At the moment O, on the other hand, both the applied E.M.F. and the condenser P.D. are zero.

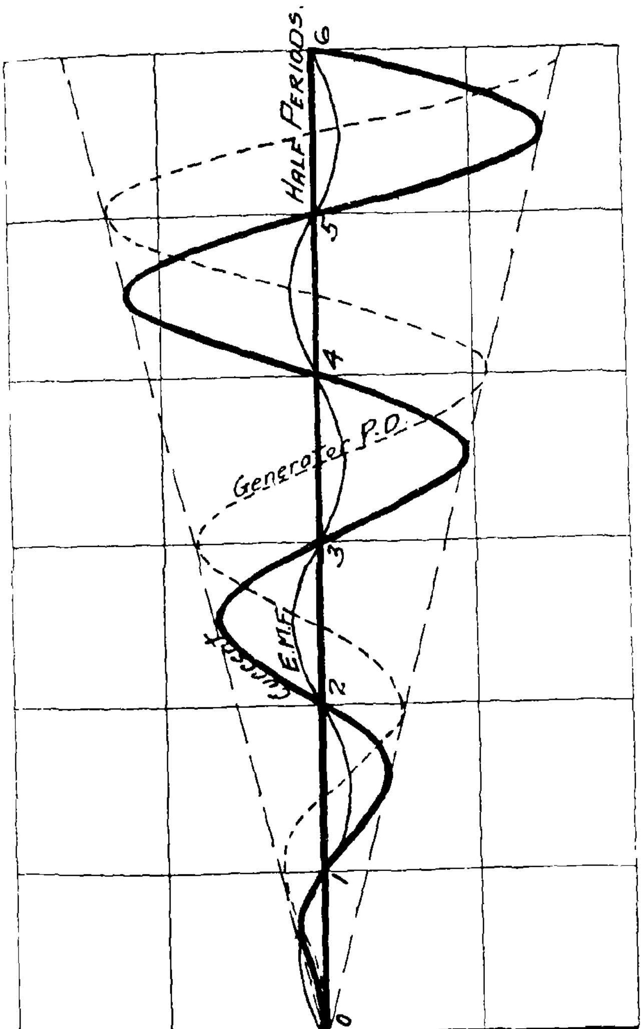


FIG. 233.

Before analysing the results of these experiments, we think it desirable to draw the student's attention to the following point.

1082. We have only shown the results obtained when the applied E.M.F. (or torque, as the case may be) is reversed in its direction at the moment when the current has fallen to zero. In other words, we have only taken the case when the time period of the applied alternating E.M.F. is the same as the natural time period of the circuit to which it is applied.

1083. **When these conditions exist in the low frequency circuit of a spark transmitter, the circuit is said to be in resonance.** As no useful object would be served by taking a number of other cases and showing the results which would be obtained if the circuit was out of tune, we will content ourselves by tabulating the important deductions which can be drawn from these experiments.

1084. By a careful study of the foregoing, and more particularly of the final results illustrated in Figs. 232 and 233, the following points are evident :

(1) **The applied E.M.F. is exactly in phase with the current flowing through the circuit.** Thus when the applied E.M.F. is at its maximum, the current is also at its maximum for that particular half-period, and when the applied E.M.F. is at zero, the current is also at zero.

(2) **The condenser P.D. is one quarter of a complete period, or 90°, out of phase with the applied E.M.F. ;** thus when the condenser P.D. is at its maximum for any particular half-period, the applied E.M.F. is at zero.

Since the current is in phase with the applied E.M.F.

it follows that **the condenser P.D. is at its maximum when the current is at zero.**

(3) The current and also the condenser E.M.F. grow to a greater and greater value at each successive half-period, and will continue to grow indefinitely so long as the applied alternating E.M.F. is maintained.

(4) The condenser P.D. at the end of the first half-period rises to a value about 2·3 times the effective value of the generator E.M.F.

1085. As already pointed out, **these conditions are true only if there is no resistance in the circuit, and only when the frequency of the applied E.M.F. is the same as the natural frequency of the circuit to which it is applied.**

Fig. 233 represents the phase relation and the growth of the charging current and condenser P.D., of a circuit in which there are no losses and in which the alternator frequency is in resonance with the circuit to which it is connected.

1086. It will be seen that the current falls into step with the electromotive force at the end of the first half-period, during which a certain quantity of electricity is forced into the condenser, and that when this quantity flows back again it is helped in this reverse direction by the applied electromotive force, which has reversed its direction at the same moment, and produces an additional quantity in this reverse direction. The result is that the swings of current become greater and greater, without limit, as the alternator is putting more and more energy into the circuit and none is being lost. This is not necessarily the case with any oscillatory circuit excited by an alternator ; it only occurs when the frequency of the alternator and the natural frequency of the oscillatory circuit are the same.

1087. If the circuit has any resistance, and in practice, of course, all circuits have a certain amount of resistance, then it is evident that energy will be lost in overcoming this resistance so long as the current is flowing through the circuit.

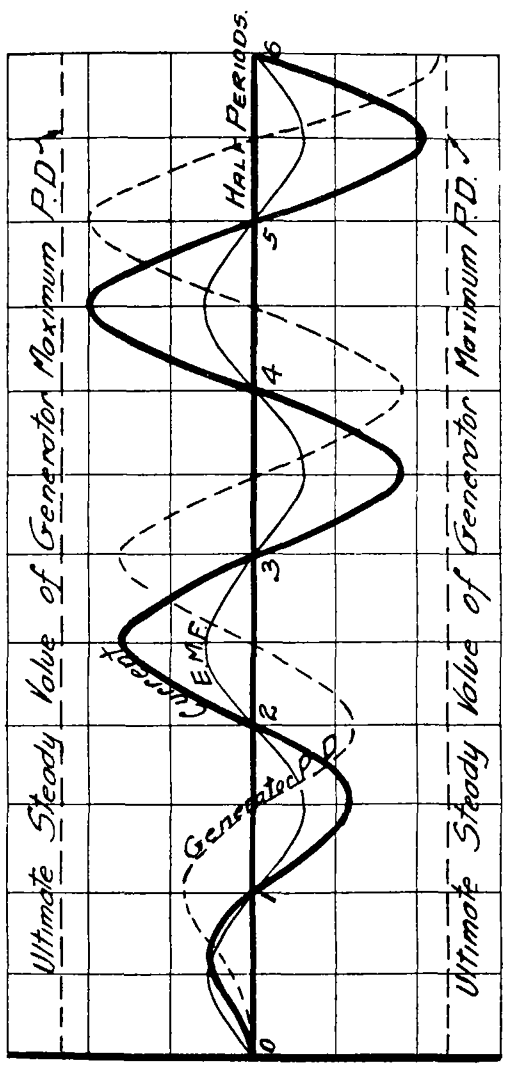
1088. Now the amount of energy lost depends upon two things: (1) the amount of resistance in the circuit, and (2) the amount of current which flows through that resistance. The resistance remains constant the whole time; but since the current, as we have shown, increases with each half-period, the amount of energy lost during the half-period will also increase with each successive half-period.

1089. Obviously **the time will be reached when the energy lost in the circuit during each half-period is equal to the energy supplied by the alternator during that half-period.** In other words, the time will be reached when the alternator is only making good the lost energy.

1090. It follows, therefore, that the effect of resistance in the circuit will be that the current, instead of indefinitely increasing in value with each successive half-period, will only approach a limited maximum value. It follows also from this that the condenser P.D. will also only approach a limited maximum value.

1091. The curves representing the growth of the current and the condenser P.D. under these conditions are shown in Fig. 234, from which it will be seen that, except for the amplitude of the current and E.M.F. curves, all the other features of the curves remain as before.

In this diagram we have illustrated the case in which the current and voltage swings, for all practical purposes, reach their maximum amplitude during the 3rd cycle



Ultimate Steady Value of Generator Maximum P.D.
Ultimate Steady Value of Generator Maximum P.D.
HALF PERIODS.
Generated P.D.
E.M.F.
0
1
2
3
4
5
6

Fig. 234.

or 5th half-cycle, and this can be taken as a typical example of what would occur in the circuits of an ordinary commercial transmitter if the spark-gap were opened wide enough to prevent any discharge of the condenser in the oscillatory circuit.

EXCITATION OF SPARK TRANSMITTERS

1092. On page 86, Part I., we discussed briefly a method of energising an oscillatory circuit, and we showed how this could be accomplished by charging up the condenser of that circuit, using a spark-gap in conjunction with an induction coil for that purpose.

1093. Although the induction coil has many advantages over the alternator and transformer to recommend it as a useful instrument for this purpose in small sets up to 100 watts or so, these advantages rapidly disappear when more powerful transmitters are required.

One of the chief drawbacks to an induction coil is the difficulty of satisfactorily interrupting the primary circuit, the contacts of the interrupter requiring continual attention even with small coils. With powerful coils this difficulty is very much enhanced, more especially when a station is required to transmit for long periods without a pause.

1094. By using an alternating current dynamo in conjunction with a transformer all these difficulties are done away with. Many new problems, however, arise which require careful consideration if satisfactory results are to be obtained, and since practically all spark transmitters of upwards of 350 watts output use this form of generator, and since the smooth and efficient working

of such transmitters depends to a very great extent on the correct adjustment of the whole charging circuits, the student is advised to take particular pains to master, not only the details of each instrument separately, but also the question of the balance of the circuit as a whole.

Importance of Resonance in Low-frequency Circuits

1095. In order to produce a succession of sparks at the spark-gap of an oscillatory circuit it is most convenient to use some form of electric generator which produces an E.M.F. varying periodically from zero to the required maximum voltage.

In this book it will be sufficient if we consider the two types of generators most commonly used for this purpose, viz. the induction coil and the alternator.

If the wave form, or E.M.F. curves, of these two types of generators be compared, a great difference in the two will be seen.

1096. The rise and fall in the voltage across the terminals of an induction coil is very sudden and rapid, and, moreover, a considerable pause occurs before the next impulse is produced. On the other hand, the rise and fall in the voltage across the terminals on an alternator is gradual and symmetrical and is spread out over the whole period between the sparks.

Whichever type of generator be used its function is the same, namely, to charge up the condenser. Owing to the different characteristics of the two types of generators, however, very different conditions are necessary to produce the best results in the two cases.

1097. A simple mechanical analogy will serve to illus-

trate the point. Let us suppose that instead of producing current oscillations in an oscillatory circuit, we wish to make a ball bounce on the floor. To get the biggest bouncing effect, we must pitch the ball up as high as possible to begin with. If we take the bouncing of the ball as analogous to the current oscillating in the oscillatory circuit, we can compare the action of pitching up the ball to the action of charging the condenser.

One way would be to hit the ball with a bat. This method can be compared with the method of charging a condenser from an induction coil, because if the action be analysed, it will be seen that the force applied to the ball would be sudden and short in duration.

Another way would be to throw it up; and this method can be compared with the method of charging a condenser from an alternator, because the pressure applied to the ball would be gradual and spread out over the whole length of time during which the ball is in one's hand.

1098. Now in the former case it is principally a matter of hitting the ball as hard as possible to project it to the maximum height, and similarly when an induction coil is used to charge the condenser, it is principally a matter of getting the coil to give the maximum "voltage kick."

In the latter case, however, it is not merely a matter of putting as much force as possible into the ball, but it is also a matter of adjusting the throw to suit the weight of the ball. Thus it is not the strongest man who can throw a cricket ball the farthest, but the man who has been trained to apply his strength to the best advantage during the time when the ball is in his hand.

Owing to the light weight of a cricket ball, the process of throwing it is so rapid that it is difficult to analyse

what takes place; therefore it will illustrate our point better if we suppose that the ball we are throwing is a large wooden one of considerable weight.

1099. In order to throw such a ball to the maximum height with the least exertion we should start swinging the ball at arm's length backwards and forwards, putting a certain amount of energy into it throughout the whole time. The ball would swing to a definite time period depending upon the length of one's arm, and we should adapt the force we applied to it in resonance or in tune with its natural swing until, when the amplitude of its swing were big enough, we should release it.

The particular point to notice in this analogy is that **to get a maximum result for a given effort the force must be applied to the ball in resonance with the natural swing.**

1100. Conditions very similar to these are obtained when an alternator is used to charge the condenser of an *oscillatory circuit. To get the maximum charging effect* for a minimum expenditure of electromotive force the frequency of the applied E.M.F. must be in resonance with the circuit to which it is applied. **The process of Resonance consists in getting up a swing.**

1101. Let us take the simplest possible case and suppose that the condenser C (Fig. 235) of an oscillatory circuit, C, L, S, is connected directly to the terminals of an alternator D.

1102. Now there are two distinct circuits to be considered: (1) the low-frequency or **charging circuit,** consisting of the alternator D and the condenser C; (2) the high-frequency circuit, consisting of the condenser C, the inductance L, and the spark-gap S.

1103. **Each** of these circuits has a definite time period of its own (*vide* Part I. paragraph 252), that

of the charging or low-frequency circuit depending upon the capacity of the condenser C and the inductance of the alternator D, and that of the oscillatory circuit depending upon the capacity of the condenser C and the inductance of the jigger-primary L.

1104. In the case of high-frequency or oscillatory circuits we have shown that the frequency of the oscillations vary in practice from about 3,000,000 per second for producing very short wave-lengths of 100

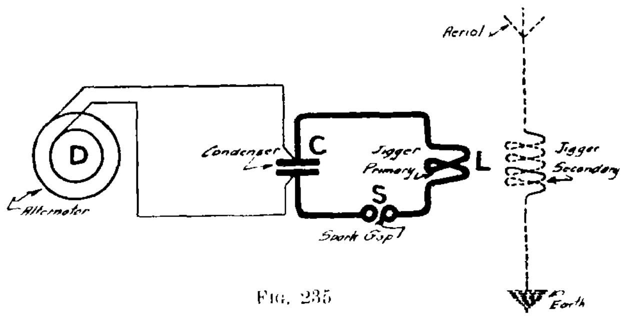


Fig. 235

metres, to about 15,000 per second for producing very long wave-lengths of 20,000 metres.

1105. In the case of low-frequency or charging circuits the frequency is governed to a large extent by the spark frequency it is desired to produce; this varies in practice between about 100 cycles per second to 500 cycles per second.

1106. It will be seen, therefore, that the frequency of the oscillatory circuit is at least many hundreds of times greater than that of the alternator circuit. **Beyond this difference in frequency, however, there is no fundamental difference between an alternating current and an oscillating current.** The terms "alternating" and

"oscillating" are used merely for the purpose of distinguishing the charging circuits from the wave-producing circuits.

1107. It may be asked then: "Why cannot an ordinary alternator be used for the direct production of electric waves?" The reason is that the wave-length produced, which, as we showed in Part I. paragraph 232, is inversely proportional to the frequency, would be so great that if an alternator of normal frequency were used, the difficulty and expense of erecting an aerial to radiate such a wave-length efficiently would be out of all proportion to the advantages gained.

1108. Take, for example, an alternator having the comparatively high frequency of 500 cycles per second. Applying the formula given in paragraph 232, viz. wave-length = velocity ÷ frequency, it will be found that the wave-length in this case would be 600,000 metres. An aerial suitable for radiating this wave efficiently would have to be about 60,000 metres, or roughly 40 miles long.

1109. On the other hand, the difficulty in the construction of an alternator of a high enough frequency to produce a shorter wave-length becomes greater as the frequency is increased, and although high-frequency alternators producing 100,000 cycles per second have been constructed with some success, there is much to be accomplished before designers can produce machines having frequencies high enough to make their use practicable for comparatively small Wireless Telegraph stations.

1110. Our object, however, is to familiarise the student with present-day practice, so no advantage will

be gained by further discussing these special machines, and the matter is only mentioned to accustom the reader to the fact that there is no fundamental difference between a low-frequency or alternating current and a high-frequency or oscillating current.

1111. An alternator will produce electrical impulses of a definite frequency quite apart from the natural frequency of any circuit to which it is connected. Therefore in order to obtain resonance in the charging circuit it is evident that either **the frequency of the alternator must be adjusted to the natural time period of this circuit,** or else **the natural time period of the circuit must be adjusted to suit the frequency of the alternator.** The problem is, in fact, similar to the problem of tuning up the primary oscillatory circuit of a transmitter to the aerial circuit, the only difference in the two cases being one of frequency.

1112. In Part I. paragraph 259 we showed that the wave-length produced by an oscillatory circuit

$$\lambda_m = 1885 \sqrt{C_{(mf)} L_{(mh)}}, \qquad \text{(A)}$$

where λ = wave-length in metres, $C(mf)$ = capacity in microfarads, and $L(mh)$ = inductance in microhenries.

1113. In Part I. paragraph 234 we showed that the length of an aether wave is equal to the velocity of light divided by the number of waves per second, *i.e.* the frequency; and since this velocity is 300,000,000 metres per second, it follows that

$$\lambda_m = \frac{300,000,000}{n},$$

where n = frequency or cycles per second.

By substituting this value for λ_m in the equation (A) given above we get

$$\frac{300{,}000{,}000}{n} = 1885\sqrt{C_{(mf)}L_{(mh)}},$$

or
$$n = \frac{3 \times 10^8}{1885\sqrt{C_{(mf)}L_{(mh)}}}. \qquad \text{(B)}$$

1114. Both these equations (A) and (B) apply equally to the oscillatory circuit whose function it is to energise the aerial and to the alternator circuit whose function it is to energise the oscillatory circuit.

We have already pointed out that the frequency of the oscillatory circuit is, in practice, many hundreds of times greater than that of the alternator. It is evident, therefore, that the values of either the capacity or the inductance or of both in the two circuits must be entirely different.

1115. A study of the diagram in Fig. 235 will show the student that **the condenser is common to both the high-frequency and low-frequency circuits.** It follows, therefore, that the inductance of the low-frequency circuit must be very much greater than that of the oscillatory circuit, on account of the difference in the two frequencies.

1116. Now we cannot vary the capacity of the condenser to suit the inductance and frequency of the alternator without upsetting the wave-length to which the oscillatory circuit has been adjusted; therefore **in order to obtain resonance in the low-frequency circuit it is necessary to vary either the frequency of the alternator or the inductance of the charging circuit.**

1117. The frequency of the dynamo is, in its turn,

governed to a great extent by the spark frequency it is desired to produce, so that in practice it is found that both the capacity and the frequency of the charging circuit are more or less fixed. The only way left to adjust the natural frequency of this circuit to obtain resonance with the frequency of the alternator is by varying its inductance.

1118. By referring to Fig. 236 it will be seen that an extra inductance coil or "choke," "A," can be inserted in the low-frequency circuit where shown without in any way interfering with the frequency (and therefore the wave-length) of the oscillatory circuit, and this is the method most commonly adopted for obtaining resonance in the low-frequency or charging circuit of a wireless telegraph transmitter where an alternator is used as the source of energy.

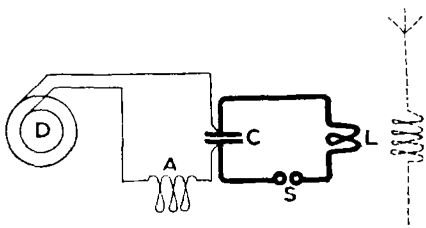


FIG. 236

1119. Let us take a practical example and work out the relative values of inductance in the two circuits.

We will suppose a wireless transmitter is required to transmit a wave-length of **300 metres.** Let us suppose that the frequency of the alternator is **200 cycles per second** and that the capacity of the condenser used is **·005 microfarads.**

1120. By transposing the formula (A) given in paragraph 1112 we get $L_{(mh)} = \frac{\lambda^2_m}{(1885)^2 C_{(mf)}}$. This formula gives the value of the inductance "L" in microhenries,

in terms of the wave-length in metres and capacity in microfarads, and can therefore conveniently be used to calculate the inductance of the oscillatory circuit, of which the wave-length and capacity are predetermined.

1121. By substituting the values given in paragraph 1119 for wave-length and capacity, we get

$$L = \frac{(300)^2}{(1885)^2 \times \cdot 005} = \mathbf{5\ microhenries}\ \text{(about).}$$

1122. In the case of a low-frequency circuit, the quantities known are the frequency and the capacity, and therefore we can use the formula (B), given in paragraph 1113, for calculating the inductance required to produce resonance. By transposing this formula we get

$$L_{(mh)} = \frac{9 \times 10^{16}}{n^2 \times (1885)^2 \times C_{(mf)}},$$

which gives the value of the inductance "L" in microhenries, in terms of the frequency n in cycles per second and the capacity C in microfarads.

1123. By substituting the values given in paragraph 1119 for the frequency and the capacity, we get

$$L = \frac{9 \times 10^{16}}{(200)^2 \times (1885)^2 \times \cdot 005}$$
$$= \mathbf{127 \times 10^6\ microhenries}\ \text{(about).}$$

1124. It will be seen from these results that in the particular example taken above the inductance of the alternator circuit necessary to produce resonance between the alternator and the condenser it is charging, is approximately 25,000,000 times greater than that of the oscillatory circuit necessary to produce a wave-length of 300 metres with the same condenser.

1125. Owing to the relatively small values of the inductance met with in practice in oscillatory circuits, the microhenry, which is one-millionth part of a henry, is usually taken as a unit of inductance in describing oscillatory circuits.

1126. When dealing with low-frequency circuits, it is usual, for convenience, to take the henry as the unit of inductance; thus, in the example given above, the inductance of the alternator circuit would be stated as

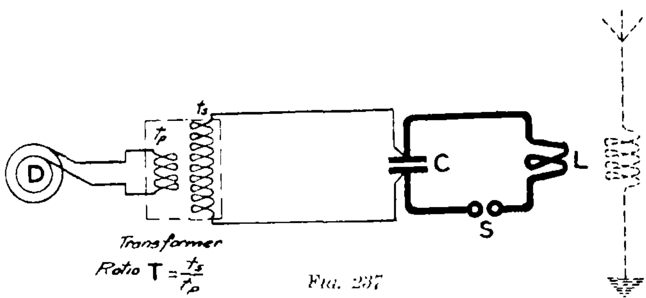


Fig. 237

127 henries, and that of the oscillatory circuit as **5 microhenries.**

1127. In paragraph 1118 we mentioned that the usual method of obtaining resonance in the low-frequency circuit is by the insertion of an inductance coil, or, as it is commonly known, a choke coil, in series with the dynamo. The value of the total inductance necessary to produce resonance depends, as we have shown, upon the frequency of the dynamo and the capacity of the condenser which it is charging. Only a part of this inductance, however, has to be supplied by the choke coil, because **the windings of the armature of the alternator are in themselves highly inductive,** and since these windings form part of the charging circuit, their in-

ductance forms part of the total inductance of the circuit. The choking coils, therefore, will only have to supply the difference between the total inductance required and that supplied by the armature of the alternator.

1128. This is assuming that the alternator is connected directly to the condenser. In practice, however, the alternator is always connected to the condenser through a transformer; that is to say, the alternator is connected to the primary terminals of a step-up transformer, the secondary terminals of which are connected to the condenser, as shown in Fig. 237.

1129. The reason for this will be evident if we take a practical example, and work out the value of the voltage to which the condenser must be charged. Let us suppose that the transmitter we were considering in paragraph 1118 is one of ·5kw (500 watts).

1130. Now in Part I. paragraph 286 we show that the power given to an oscillatory circuit is proportional to the capacity of the condenser, the square of the voltage to which the condenser is charged, and the number of times per second that the condenser is discharged.

1131. If the power be expressed in watts, the capacity in farads, then

$$W = \tfrac{1}{2}CV^2S;$$

where W = power in watts;
C = capacity in **farads**;
S = number of times per second the condenser is discharged, or in other words, the number of sparks per second;
V = Volts to which condenser is charged;

or $W = \frac{1}{2}\frac{CV^2S}{10^6}$, where C = capacity in **microfarads**.

1132. By applying this formula to the example we

are considering, and assuming that the spark-gap is arranged to break at every half period, thus giving a spark frequency of 400 per second, or double the frequency of the alternator, it can be calculated from the above that the potential to which the condenser of ·005 microfarads must be charged at each half period is 23,000 volts (approximately).

1133. For reasons which we have already explained (*vide* paragraph 1079), if the low-frequency circuit is in resonance with the frequency of the alternator, the voltage to which the condenser is charged at the end of the first half period will be, approximately, 2·3 times the R.M.S. value of the E.M.F. generated by the alternator. In this case, therefore, the alternator will be required to generate 10,000 volts.

1134. Now the construction of a small alternator to generate such an extremely high voltage would present very considerable difficulties, more especially as regards the insulation of the windings. In addition to this, considerable difficulty would be experienced in the design of a manipulating key suitable for rapidly interrupting the low-frequency circuit, and which would avoid danger to the operator using it.

1135. For these and other considerations it is usual to generate at a very much lower voltage, and to use a "step-up" transformer to obtain the required voltage across the condenser.

1136. Now the whole effect of including the transformer in the charging circuit is not, perhaps, at first sight apparent.

In the first place, there is the inductance of the transformer itself, which, according to its design, may or may not be considerable. In paragraphs 978 to 983, in

describing the transformer we showed how its effective inductance depends entirely upon the magnetic leakage in the iron circuit, and how this can be controlled within very wide limits by the design of the instrument.

1137. In any case, whatever inductance the transformer we use possesses is added to that of the dynamo, so that any extra inductance in the form of choking coils which may be included in the circuit will only have to supply the difference between the total inductance necessary to produce resonance, and that supplied by the transformer and alternator.

1138. In the second place, the insertion of a transformer in the charging circuit **entirely alters the effective value of the inductance of the alternator, or of any other inductance included in the primary circuit.**

Effect of Transformation Ratio on Resonance in the Low-frequency Circuit

1139. By referring again to Fig. 237 it will be seen that when the transformer is used to obtain the necessary voltage across the condenser, the low-frequency circuit is divided into two separate parts, viz. : **the low-tension circuit,** consisting of the alternator and transformer primary; and **the high-tension circuit,** consisting of the transformer secondary and the condenser. **These two circuits are so closely coupled together inductively that they can be considered as one circuit so far as resonance is concerned;** that is to say, any inductance or capacity connected in the primary circuit will have exactly the same effect on the natural time period **of the circuit as a whole,** as if an **equivalent** inductance or capacity were connected in the secondary circuit.

1140. We use the word "equivalent" because either a capacity or an inductance will have an **entirely different effective value** in the two circuits. The relative value depends upon the relative values of the voltage or current in the primary and secondary circuits of the transformer, or, in other words, upon the transformation ratio of the transformer.

1141. If we assume that the primary of the transformer is the low-voltage winding, and that the secondary is the high-voltage winding, that is to say, that the transformer is a "step-up" transformer, as is usually the case in wireless transmitters, and if the transformation ratio is "T," then it can be shown that *any inductance connected in series with the primary winding will have the same effect on the natural frequency of the circuit as if an inductance* **T^2 times greater** *were connected in the secondary circuit.* Further, it can be shown that a condenser connected in the primary circuit will have the same effect on the natural frequency of the circuit as if a condenser **T^2 times smaller** were connected in the secondary current.

1142. This effect which the transformer has may at first sight seem strange, but exactly analogous conditions can be arranged in a mechanical system, and it will perhaps be easier to understand the matter if we take the mechanical case first.

1143. When describing the theory of the transformer in paragraph 976, we compared its action in an electrical circuit to that of a gear box in a mechanical system; also the student will by now be well acquainted with the electrical equivalents of the mechanical properties of mass, flexibility, torque, and speed.

1144. Let us then imagine a mechanical system to

represent our electrical circuit, as shown in Fig. 238, where a handle, as a means of applying torque, is mounted on what we may call the driving or **primary shaft** of the gear G, and a flywheel M and a spring F are mounted on the driven or **secondary shaft** of the gear box.

1145. If the ratio of the gear is **one to one,** then it is evident that any torque applied to the primary shaft will be transmitted by the gear to the secondary shaft at an equal value. Further, the speed of the

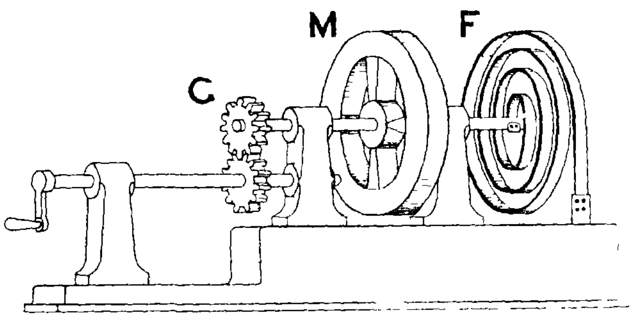


Fig. 238.

primary shaft will be equal to that of the secondary shaft at any instant.

1146. If now we carry out, on this mechanical system, the same experiments described in paragraphs 1047 to 1075, we shall obtain results exactly similar to those noted in those experiments. It will be found that the two shafts and gear box act exactly as though they formed only one rigid shaft, with the one exception, that in this case the primary shaft revolves in the opposite direction to the secondary shaft. The point we wish to draw attention to is that the **time period** of the system would

remain the same, whether the flywheel and spring were both mounted on the secondary shaft as shown in Fig. 238, or the flywheel on the primary shaft and the spring on the secondary shaft as shown in Fig. 239.

If, on the other hand, the ratio of the gear is not one to one, then different results will be obtained.

1147. For the purpose of explanation, let us suppose that the ratio of the gear is 1 to 2. In this case it is evident that any **torque applied to the primary shaft will be transmitted by the gear to the secondary**

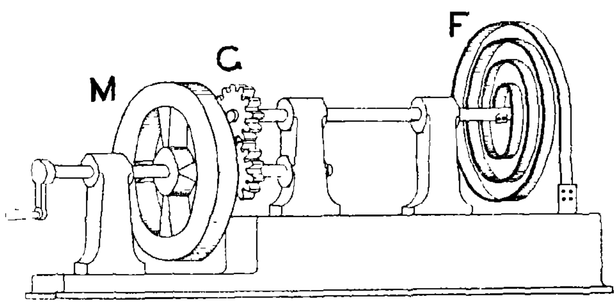


Fig. 239.

shaft as a torque twice as great, and *vice versa,* any torque applied to the secondary shaft would be transmitted by the gear to the primary shaft as a torque one half as great. Also for **every revolution made by the primary shaft, the secondary shaft will only rotate one half a revolution,** from which it follows that **at any moment the speed of the primary shaft would be twice that of the secondary shaft.**

Let us first take the case when both the flywheel and the spring are mounted on the secondary shaft as shown in Fig. 240.

1148. Now if a uniform torque be applied to the handle, the two shafts will rotate (in opposite directions), the primary shaft revolving at twice the speed of the secondary shaft. Further, the speed at which they rotate will increase until the back torque exerted by the spring balances the applied torque. After this the speed falls until the two shafts come to rest.

1149. Although, owing to the gear ratio, the torque applied to the secondary shaft will be twice that applied

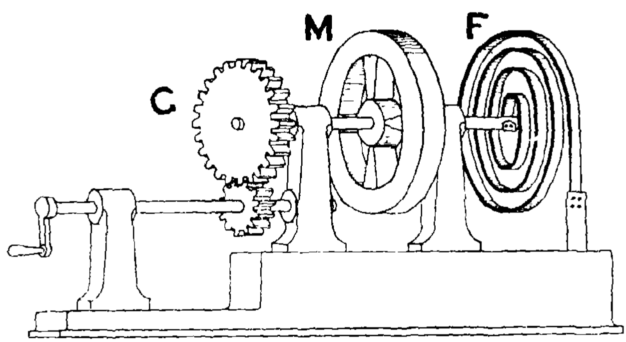


Fig. 240.

to the primary shaft, yet the time period of the system will be the same as if the gear box were not there, because *the time period, as explained in paragraph 1062, is entirely independent of the magnitude of the applied torque.*

Let us now take the case when the flywheel is mounted on the primary shaft, and the spring on the secondary shaft, as shown in Fig. 241.

1150. *If the same uniform torque as before be applied to the primary shaft, then it will be found—*

(1) That the rate at which the speed of the flywheel

increases will be one half that at which it increased before, because the rate of increase in the speed depends upon the magnitude of the applied torque, and owing to the action of the gear box the torque applied to the flywheel in the former case was double that of the applied torque, while in the latter case it is only equal to it.

1151. (2) **The number of revolutions which the secondary shaft must make before the back torque of the**

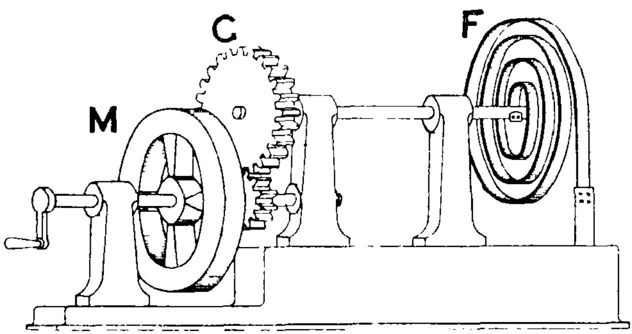


FIG. 241.

spring balances the applied torque, will be the same as in the first case, because in both cases the spring is mounted on the secondary shaft.

1152. (3) Since the flywheel is now mounted on the primary shaft, and since the number of revolutions made by the primary shaft is, owing to the action of the gear box, always double the number made by the secondary shaft, it follows from (2) that in this case **the flywheel must make double the number of revolutions** before the back torque of the spring balances the applied torque, *i.e.* before the flywheel has attained its maximum speed.

1153. At first sight it would appear from (1) and (3) that since the rate of increase in the speed of the flywheel is now one half what it was, and that the number of revolutions it has to make is now twice what it was, that it would take **four** times as long for the flywheel to reach its maximum speed, and therefore that the time period of the system would be four times what it was.

1154. This would be true only if the length of time taken were directly proportional to the number of revolutions made, and inversely proportional to the rate of increase in the speed, *i.e.* if

$$t = \frac{R}{i},$$

where t is the length of time, i the rate of increase in the speed, and R the number of revolutions.

1155. This, however, is not true, because if the rate of increase in the speed is less, the length of time taken to make a given number of revolutions is more, therefore the speed will be increasing for a proportionately greater length of time. Now, the number of revolutions made will be the average speed multiplied by the length of time the shaft is revolving; also the average speed at which it revolves (assuming that it starts from a standstill) will be proportional to the average rate of increase of speed multiplied by the length of time it is accelerating. It follows, therefore, that the number of revolutions (R) is equal to the average rate of increase of the speed multiplied by (time)^2. That is to say, instead of

$$t = \frac{R}{i}, \text{ actually } t = \sqrt{\frac{R}{i}}.$$

1156. By applying this formula, then, to the experi-

ment made when both flywheel and spring were mounted on a secondary shaft, if we take the rate of increase in the speed of the flywheel as being 1, and the number of revolutions it makes before reaching its maximum speed as being 1, we get

$$t=\sqrt{\frac{1}{1}}=1.$$

1157. In the second case, however, when the flywheel is mounted on the secondary shaft, the equation becomes

$$t=\sqrt{\frac{2}{\frac{1}{2}}}=2.$$

1158. Thus it will be seen that by mounting the same flywheel on the primary shaft instead of on the secondary shaft, when the gear ratio is 2 **the time period of the system as a whole has been doubled.**

1159. Similarly, it will be found that if the gear ratio were four to one instead of two to one, the time period of the system as a whole would be increased four times; and by taking other examples it can be shown that if the flywheel be mounted on the primary shaft and the spring on the secondary shaft **the time period will always be G times what it is when both flywheel and spring are mounted on the same shaft**; where G = the gear ratio.

1160. Exactly analogous results are obtained in an electrical circuit consisting of an inductance L and a condenser C, if a transformer be inserted in the circuit, as shown in Fig. 242.

1161. In such a case **the time period of the circuit, if all the inductance is connected in the primary and all the condenser in the secondary circuit of the trans-**

former, as shown in Fig. 242, will be T times what it is when both inductance and condenser are connected in the secondary circuit, as shown in Fig. 243, where T is the transformation ratio.

1162. From this it is easy to see that such a circuit will act as a simple circuit, consisting of a condenser and an inductance only, that is to say, it will have a definite time period depending upon the value of the inductance and the value of the capacity. But since the effect of a given inductance depends upon whether it is connected in the primary or secondary circuit, we must make an allowance for the effect of the transformer.

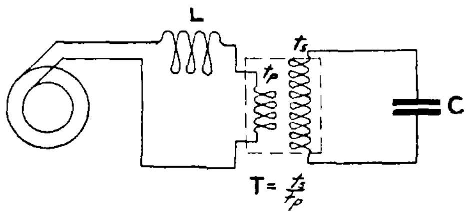


Fig. 242.

1163. Now the time period P of such an electrical circuit is, as we have previously shown, proportional to the wave-length λ of that circuit. And since $\lambda \propto \sqrt{CL}$, it follows that also $P \propto \sqrt{CL}$, and therefore that $L \propto \frac{P^2}{C}$, from which it is evident that **the inductance of a circuit in which the condenser is fixed is proportional to the square of the time period.**

But we have shown that the time period of the circuit illustrated in Fig. 242 will be reduced T times if the inductance L be connected in the secondary circuit, as shown in Fig. 243.

1164. *It follows, therefore, that the effective value of the inductance L is T^2 times greater if connected in the primary circuit than if connected in the secondary circuit.*

1165. In other words, if the condenser be connected in the secondary, or "low-current" circuit, then **any inductance connected in the primary or high-current circuit has the same effect as if an inductance T^2 times greater were connected in the secondary circuit.** Similarly, *any condenser connected in the primary circuit would have the same effect as if a capacity T^2 times smaller were connected in the secondary circuit.*

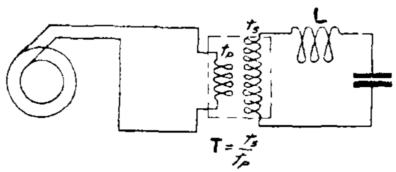


FIG. 243.

This effect can also be shown by considering the matter from an energy point of view.

1166. When a current is flowing in the primary circuit it represents so much stored energy, depending upon the amount of current, and the inductance of the circuit in which it is flowing. If L_p represents the inductance of the primary circuit, and i_p represents the primary current, then the energy at any moment will be $E = \frac{1}{2}L_p i_p^2$.

1167. Similarly, the energy in the secondary circuit will be $E = \frac{1}{2}L_s i_s^2$, where L_s is the inductance and i_s the current in the secondary circuit. Now the energy is really distributed throughout the circuit as a whole, and the transformer simply alters its proportions, but in dealing with it we can simplify calculations by either considering it as being all in the primary circuit or as being all in the secondary circuit. Thus if we consider

it as being in the primary circuit $E = \frac{1}{2}L_p i_p^2$, or if we consider it as being all in the secondary circuit $E = \frac{1}{2}L_s i_s^2$. **Since the energy is the same in both cases,** it follows that $L_s i_s^2 = L_p i_p^2$.

1168. Now the relative currents in the two circuits, as we have shown, are proportional to the transformation ratio, so that $i_p = i_s \times T$, where T is the transformation ratio.

1169. Thus by substituting these values in the above equation we can get two equations, one giving **the value of the inductance in the secondary in terms of the primary inductance and the transformation ratio,** and the other giving the equivalent value of the inductance in the primary in terms of the secondary inductance and the transformation ratio, because

$$L_s i_s^2 = L_p i_p^2 ;$$

but $$i_p = (i_s \times T),$$

$$\therefore \quad L_s i_s^2 = L_p (i_s \times T)^2 = L_p i_s^2 \times T^2,$$

$$\therefore \quad L_s = L_p \times T^2 ;$$

or, by transposing, $$L_p = \frac{i_s}{T^2}.$$

1170. We may now see how this rule can be applied to a practical case. Let us take for an example the particular case we were considering in paragraph 1118, where the charging circuit consisted of a dynamo connected to a condenser through a choke coil. We can represent this circuit, so far as its natural frequency is concerned, by an inductance connected across a condenser as shown

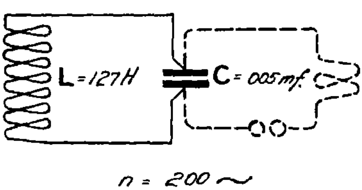


FIG. 244.

in Fig. 244, where the inductance L represents the total inductance of both the dynamo and the choke coil, which in this particular case is 127 henries, and the capacity C represents the capacity of the condenser which the dynamo is charging, which in this particular case is ·005 microfarad. Now the natural frequency

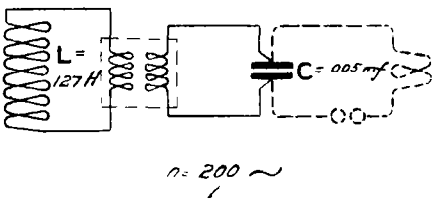


FIG 245.

of this circuit, as we have shown, is 200 periods per second.

1171. If now we disconnect the condenser from the inductance, and connect the inductance to the primary of

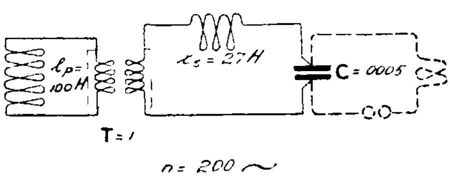


FIG. 246

a transformer, and the condenser to the secondary of the transformer, as shown in Fig. 245, the circuit, as a whole, will still have a certain natural frequency. If the ratio of the transformer is 1 - 1, that is to say, if T = 1, and if there is no magnetic leakage in the transformer, the natural frequency will be exactly the same as when the condenser was directly connected to the inductance.

Thus it will be seen that **in this case the transformer does not affect the natural frequency of the combination.** Evidently, therefore, we can put some or all of the inductance in the secondary side of the transformer, as shown in Fig. 246, and the natural frequency will still be the same so long as the sum of the two inductances, l_p and l_s is the same as before.

1172. If, however, the ratio of the transformer is not 1 – 1, but is, say, 1 – 100, that is to say, if T = 100, and if once more the inductance is all connected in the primary circuit, and the condenser is connected in the secondary circuit, as shown in Fig. 247, then the natural

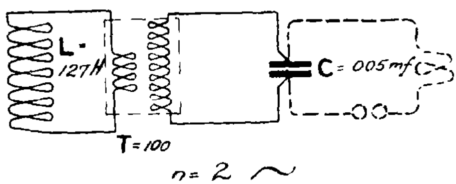


Fig. 247.

frequency of the circuit will be **100 times lower,** because it will act as though either an inductance 10,000 times greater than L (*i.e.* 1,270,000 henries) were connected across the condenser C, or it would act as though a condenser 10,000 times greater than C (*i.e.* 50 microfarads) were connected across the inductance L.

1173. Again, if in this case, instead of leaving all the inductance in the primary side of the transformer, we divide it into two parts, as before, and leave l_p in the primary and put l_s in the secondary, as shown in Fig. 248, it is obvious from the above that the natural frequency of the circuit would then be the same as one which consisted of the same capacity C and an inductance

of 10,000 $l_p + l_s$, or as one which consisted of an inductance of $l_p + \frac{l_s}{10,000}$ and a capacity of 10,000 C.

1174. Let us now see how this effects the design of the transmitter shown in Fig. 237. If, as before, the capacity of the condenser is ·005 mf. and the frequency of the alternator 200, then, as we showed in paragraph 1123, it is necessary to have an inductance equivalent to 127 henries **in the charging circuit, as a whole,** in order to obtain resonance.

1175. If the dynamo were directly connected to the condenser, then this amount of inductance would have

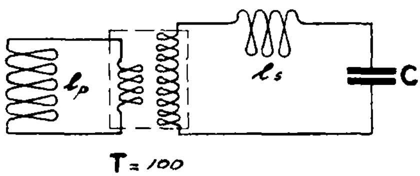


FIG. 248.

to be made up between the dynamo and the choke coil; but if, as in this case, we use a transformer to step up the voltage applied to the condenser, then the total inductance, if all is connected in the primary circuit, would only have to be $\frac{1}{T^2}$ times 127 henries. Thus, in this case, if the transformation ratio is 1 – 100, *i.e.* if T = 100, the inductance of the dynamo and the choke coil would have to be $\frac{127}{10,000} = \cdot 0127$ henry.

1176. On the other hand, if all of the inductance could be connected in the secondary circuit, it would have to be 127 henries; but since the dynamo will have a con-

siderable inductance of its own, the inductance necessary for connecting in the secondary circuit will be 127 henries less 10,000 times the inductance of the dynamo.

1177. Thus, if the inductance of the dynamo in this case is, say, ·01 henry (which is a reasonable value to assume), we can obtain resonance either by connecting an inductance of $\cdot 0127 - \cdot 01 = \cdot 0027$ henry in the primary circuit, or by connecting an inductance of $127 - (\cdot 01 \times 10{,}000) = 27$ henries in the secondary circuit.

1178. At first sight it would appear to be far more economical, as regards material, to put all the inductance in the primary circuit, but this is not necessarily so, for the following reason :

If the transformation ratio is 1 - 100, then the current in the secondary circuit will be 100 times less than that in the primary, so that the wire with which the secondary inductance coil is wound can be 100 times smaller cross section than that which would be necessary for the primary inductance coil; thus we could get roughly 100 times as many turns of secondary wire into the same space occupied by the primary turns.

1179. Further, the inductance of a coil is roughly proportional to the square of the number of turns with which it is wound, so that in order to get an inductance 10,000 times greater, we only require about 100 times as many turns, which, since it can be wound with a wire 100 times smaller, can be got into approximately the same space as the primary turns.

Adjustment of Resonance in Charging Circuit

1180. It is not always possible, when designing a transmitter, to estimate exactly what will be the induct-

ance of the various parts, such as Dynamo, Transformer, Choke Coils, etc.; further, instruments although made to the same designs will not always have exactly the same values of inductance on account of slight differences in workmanship and material. It is therefore usually arranged that a **variable** inductance or choke coil be included in either the primary or secondary circuit of the transformer. When, however, it is for one reason or another undesirable or impracticable to include a variable choke coil, the dynamo, transformer, and other parts of the circuit are so arranged as to give very nearly the required inductance, and the final adjustment in the tuning of the low-frequency circuit is accomplished by varying the speed of the alternator until its frequency is in resonance with the circuit.

1181. This method, however, only allows for a very limited variation. For one thing, if the speed of the alternator is increased or decreased in order to obtain a higher or lower frequency, the voltage which the alternator generates is increased or decreased in proportion. This in its turn will have the effect of increasing or decreasing the power of the transmitting set, which is, for obvious reasons, undesirable.

1182. By connecting an adjustable resistance or rheostat in series with the field coils of the alternator the voltage which it generates can be maintained at a constant value, but only over a limited range of speed. It is desirable, therefore, that the total inductance of the charging circuit is designed to be very nearly correct. The variation of the speed, however, within a limited range is a very convenient method of obtaining perfect resonance.

SPARK DISCHARGERS

1183. In Part I., paragraphs 319 to 325, we explained that the reason for including an air-gap, or, as it is better known, a "Spark-Gap," in an oscillatory circuit is to enable the condenser to be given an initial charge of electricity by creating a temporary interruption of the jigger windings, which would otherwise form a short circuit across the condenser. We also showed how at a critical voltage, depending upon its length, the insulation of the gap is broken down and a spark passes across it, converting the gap momentarily into a conductor. The condenser then discharges itself through the inductive windings and an oscillatory current flows in the circuit.

General Requirements of Spark-Gaps

1184. We mentioned in Part I. that once the resistance of the air is broken down a very small current is sufficient to maintain the spark, but there is another factor which we did not mention and which requires careful consideration. We refer to **the length of time required for the gap to resume its normal insulating properties after the current has ceased to flow through it.**

1185. Now the intense heat generated by the spark at the moment of its discharge is sufficient to volatilise some of the metal of which the spark electrodes are made.

This volatilised metal, which is a highly conductive vapour, is carried by the current across the gap and forms a conductive bridge from one electrode to the other.

1186. So long as **a certain minimum current** is passing across the gap it is sufficient to maintain the supply of vapour, and the conductive bridge is maintained, but as soon as the current is switched off, or for any other reason falls below this critical minimum value, the surrounding atmosphere rapidly cools the vapour which condenses on adjacent objects and the conductive bridge is thus broken up and dispersed.

1187. It is evident that the time taken, after the current has fallen below the critical value, for the gap to return to its original non-conductive state **will depend upon the rapidity with which the vapour is cooled.** Before, however, dealing further with this question, *i.e.* the cooling, or "quenching," as it is sometimes called, of the spark, we must first understand clearly how rapidly it should be cooled to meet the requirements of a wireless telegraph transmitter.

1188. Let us first take the case of a "plain aerial" transmitter similar to that described in Part I. page 89, where the oscillatory circuit consists of an aerial connected to an "earth" system through a spark-gap across which an induction coil is connected. As already explained, the oscillatory currents produced in such a circuit will be damped owing to loss of energy, partly in radiation and partly in the resistance of the aerial circuit.

1189. We will assume that in the particular case in view the damping is such that five complete oscillations occur before they completely die out. We will also assume that the wave-length of the aerial is 1000 feet. Since about 100,000 oscillations per second are required

to produce this wave-length, it follows that the length of time taken for a complete group of five oscillations will be $\frac{5}{100,000}$th part of a second, or **50 microseconds.** Under these conditions the curve representing the current oscillations in the aerial will take the form shown in Fig. 249, where each division of the horizontal axis represents 5 micro-seconds.

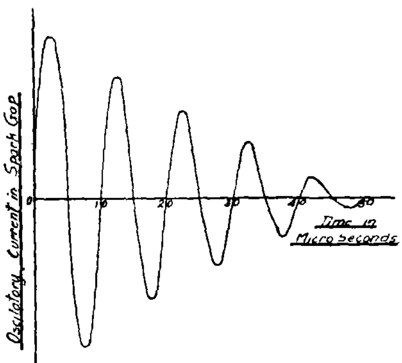


FIG. 249

1190. Referring to this curve, it will be seen that **the current passing through the gap reaches zero value at the end of each half-oscillation.** If, therefore, the spark be cooled so rapidly that at the instant the current reaches zero value the conductive bridge breaks up, we should prevent the current in the aerial from oscillating at all. This, in turn, will, of course, prevent any radiation of electric waves from the aerial. But apart from this, it would be extremely difficult, if not impossible to design a spark-gap which would cool or quench the spark so rapidly.

1191. We may say then, in general, that the length of time taken to quench the spark of a wireless telegraph transmitter must be such that it does not prevent the oscillatory current from flowing.

It is as well to point out here the relative values of the current when a condenser is discharging through an oscillatory circuit and when it is being charged.

1192. Let us take the example we have just been considering of an oscillatory circuit whose frequency is 100,000 complete oscillations per second, and the condenser of which is being charged 400 times per second: and let us suppose that the process of charging is spread out over the whole of the time interval between discharges. For the purpose of explanation let us suppose that when the condenser is fully charged it holds ·001 coulomb of electricity. Then it is evident since it takes $\frac{1}{400}$th part of a second for this quantity of electricity to flow into the condenser, that the **average** current flowing during the charging period will be ·001 × 400 amperes = **·4 ampere.**

1193. Now when the spark takes place the condenser discharges itself during the first half-oscillation, and since the frequency of the complete oscillations is 100,000 per second, it follows that the same quantity of electricity, namely, $\frac{1}{1000}$th coulomb, flows through the oscillatory circuit and through the spark-gap in $\frac{1}{200000}$th part of a second; therefore the average value of the current during the first half-oscillation of discharge is ·001 × 200,000 = **200 amperes;** thus it will be seen that in this particular case the average discharge current during the first half-oscillation is 500 times greater than the average charging current.

1194. In Fig. 250 we have endeavoured to illustrate graphically the extremely short duration of time during which the oscillatory currents are flowing, compared with the charging period and the comparative values of the charging and discharge currents. The difference between the two values, however, is so great that it has been necessary to draw the charging current to a scale 10 times that of the oscillatory current.

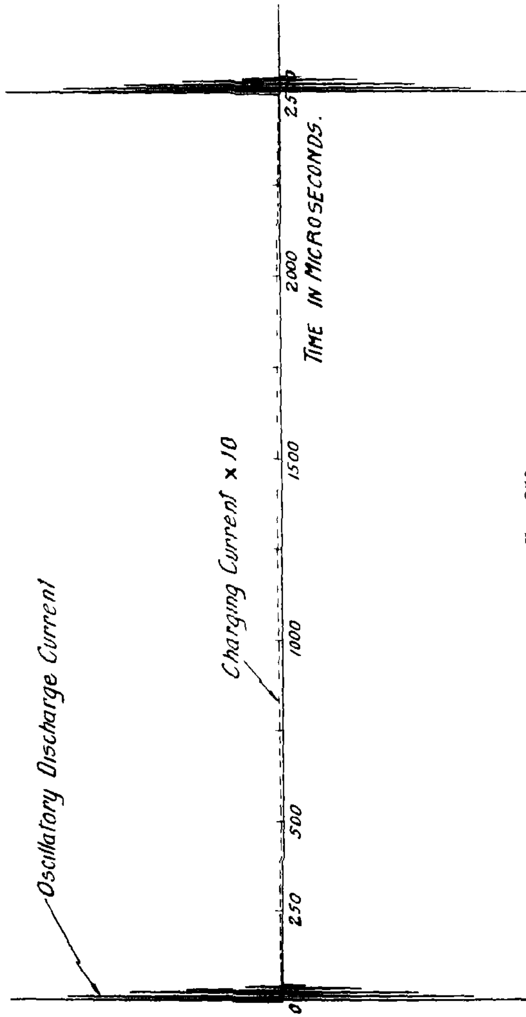

Oscillatory Discharge Current
Charging Current × 10
Time in Microseconds.
0
250
500
1000
1500
2000

Fig. 250.

1195. Owing to this short duration of the oscillatory discharge and of the heavy current flowing, the effect on the appearance of the discharge is very marked. The conductive bridge formed by this discharge has no time in which to develop fully, with the result that it collapses very rapidly when the current ceases to flow, and the discharge is thus sharply defined, making a sound like the crack of a whip, the colour being an intense white. Such a discharge is known as a "**Spark,**" to distinguish it from an "arc" discharge described below.

1196. If the spark frequency is so rapid or other conditions occur that the conductive bridge is not broken up before the next charging impulse commences, this charging current, as we have already shown, will flow through the gap. The effect of this on the appearance of the discharge, owing to the comparatively long period of time during which the current in the gap is maintained, is to cause a much greater volume of volatilised metal to be produced, with the result that the discharge is flamelike and woolly in appearance and the sound muffled and dull.

1197. When such a discharge is produced across a horizontal gap as shown in Fig. 251, the draught of air, produced by the heat of the discharge, causes it to bulge upwards in the middle, forming an arc. For this reason such a discharge is generally known as an "**arc.**" The character of these discharges will vary in degree according to the amount of current flowing through the gap, the

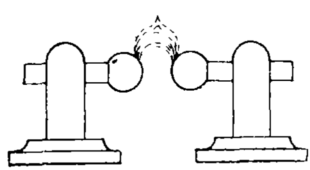


FIG. 251

duration of the discharge, and the nature of the metal of which the electrodes are made. So that although there is a very marked and distinct difference between the characteristics of a spark and those of an arc, no definite line can be drawn as to when a discharge ceases to be a spark or commences to be an arc. In practice, however, after a certain amount of experience with dischargers, *even a small amount of "arcing" in a spark* can be detected by the eye and ear.

1198. If, as already mentioned, the next charging impulse occurs before the conductivity of the gap is destroyed, then the charging current, instead of flowing into the condenser or aerial, as the case may be, will flow across the conductive bridge of the gap. In other words, the condenser would be short circuited by the gap during the charging period. If we assume that the spark frequency of the generator which is charging the aerial is 400 per second, it follows that a time of $\frac{1}{400}$th of a second, or 2500 microseconds, elapses between the commencement of one group of oscillations and the commencement of the next group. Of this time we have already shown in the example we have taken that some 50 microseconds are taken up before the oscillatory currents finally reach zero, so that apparently we have 2450 microseconds in which to destroy the conductive bridge.

1199. This length of time would be available only if the condenser could be charged instantaneously, but in practice, where an alternator is used to charge the condenser, the voltage produced, and the current flowing as a result of this voltage, is growing throughout the whole period. It is found in practice, however, that it takes an appreciable length of time before

the charging current from an alternator has **grown sufficiently to maintain the supply of vapour necessary to keep the conductive bridge intact.**

1200. It is evident, therefore, that the spark-gap of a wireless telegraph transmitter must be cooled sufficiently rapidly to destroy the conductive bridge **before the charging current has reached a high enough value to maintain the conductive bridge produced by the oscillatory discharge.**

1201. When an induction coil is used for charging the condenser, the voltage impulse does not begin—and therefore also the current does not begin to flow at all for a considerable length of time after the discharge has taken place ; in other words, there is a pause between each charging impulse. This interval is due to the fact that after the primary current of the induction coil has been interrupted at the coil contacts, it takes an appreciable length of time for the contacts to come together again. Obviously, therefore, the problem of cooling the spark-gap of a transmitter energised by an induction coil is very much simpler than if an alternator be used.

1202. So far we have examined the conditions necessary to produce a series of oscillations in a radiating or open oscillating circuit. The same rules exactly would apply in the case of a closed oscillating circuit, but the conditions in this case are somewhat different for the following reasons.

1203. A simple closed oscillating circuit, consisting of a condenser and an inductance coil, will not radiate electric waves to any appreciable extent (*vide* Part I. paragraph 289).

Therefore, provided the resistance of the closed circuit is kept low and the circuit is not coupled to any

aerial, the damping of the oscillations will be very slight compared with that in a radiating circuit. If, therefore, we insert a spark-gap in such a circuit and, as before, connect an induction coil across it, each spark will produce a very much longer train of oscillations, perhaps as many as 50 or 100 occurring with each spark.

1204. Fig. 252 shows a diagram of the oscillations which would be produced under these conditions, and it is evident that the amount of cooling necessary would, in this case, be greater than in the case of the

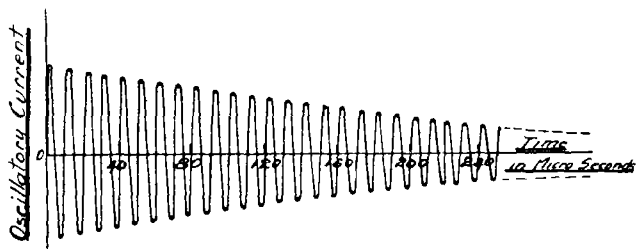


Fig. 252

highly damped oscillations illustrated in Fig. 249, not only on account of the increased length of time taken by the oscillating current, and therefore the decreased length of time available in which to quench the spark, but also on account of the fact that, owing to **the duration** of the spark, the volatilisation of the electrodes will have developed to such an extent that either more time or greater cooling effect will be required to break up the conductive bridge.

It is for this reason that when a wireless telegraph transmitter is " sparked " without any aerial connected to the secondary, difficulty will sometimes be met with in eliminating the tendency to arc.

1205. If we couple a closed oscillatory circuit to an aerial circuit as described in Part I., paragraphs 326 to 369, then, as we there pointed out, the energy in the closed or primary circuit will be transferred to the aerial or secondary circuit, where some of it will be radiated in the form of electric waves. This transference of energy takes place gradually, and its effect on the current oscillations in the primary circuit will be to damp them. At the moment when all the energy has been transferred to the secondary circuit the oscillations in the primary will have completely died down. On the other hand, as more and more energy is transferred to the aerial circuit the oscillations in the latter increase, until at the moment when the oscillations in the primary have completely died down, those in the aerial circuit are at their maximum.

1206. From this moment the energy in the aerial circuit is gradually transferred **back again to the primary circuit,** but since, while a current is oscillating in the aerial, some of the energy is being radiated in the form of electric waves, only a portion of the original energy, viz. that which has not yet had time to radiate, will be transferred back to the primary circuit. This give-and-take process continues until eventually all the energy has been radiated by the aerial, or otherwise absorbed in resistance losses in both circuits.

1207. Fig. 253 shows a diagram of the relative current oscillations which occur simultaneously in the two circuits under these conditions; the upper diagram represents the oscillations in the primary circuit, and the lower diagram those in the aerial circuit.

1208. The number of times that the energy is transferred from one circuit to the other before all is radiated,

will depend upon two things—(1) the rate at which the aerial will radiate energy, and (2) the coupling between the two circuits. The quicker the aerial radiates (and this depends upon the form of the aerial), the fewer the number of times energy will be transferred, because all the energy will be radiated in a shorter length of time. On the other hand, the closer the coupling between the two circuits, the quicker will the energy be transferred

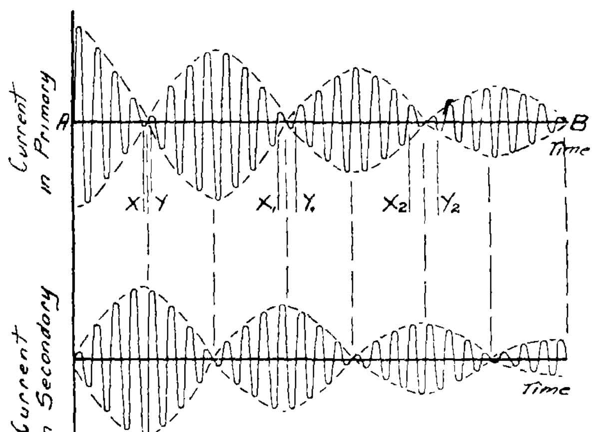


Fig. 253.

from one circuit to the other; therefore the greater the number of times will this transfer take place before all the energy is radiated.

1209. Now it is evident that this transfer of energy backwards and forwards is only possible **when the conductive bridge across the gap in the primary circuit is *maintained throughout the whole period of oscillations,*** that is, from the moment A to the moment B in Fig. 253. It will be noticed, however, that at each recurring

moment when there is no energy in the primary circuit, there will be, for a short space of time, **a very small current passing through the spark-gap.** Thus there is quite an appreciable length of time on either side of the zero point, during which the average value of the current passing through the spark-gap is in itself insufficient to maintain the conductive bridge. We may assume in the case illustrated in Fig. 253 that during the times $X - Y$, $X_1 - Y_1$ and $X_2 - Y_2$, etc., the average value of the current flowing through the gap is not enough to maintain the conductive bridge.

1210. In paragraph 1187, however, we pointed out that a definite length of time is required for the gap to resume its non-conductive state, after the current has fallen to a critical minimum value, depending upon the rate at which the gap is cooled.

1211. If, therefore, the design of the gap is such that it takes more than the time $X_2 - Y_2$ for the conductive bridge to be broken, the conditions will be such as to enable the transfer of energy as described in the preceding paragraphs to take place freely between the two circuits.

1212. A spark having these characteristics is known as a **Persistent Spark**, and the result of coupling the two circuits together under these conditions is the production of a double wave, as explained in Part I., paragraphs 370 to 394.

1213. If the design of the gap is such that it takes less than the time $X - Y$ for the conductive bridge to be broken, then the conditions will be entirely changed.

It is evident that as soon as the whole of the energy has been transferred to the aerial, the conductivity of the gap will be destroyed and the energy which is now in the aerial cannot return to the primary, and the

current, therefore, will continue to oscillate in the aerial circuit until the whole of the energy has been radiated in the form of electric waves or lost in resistance.

1214. In this case the diagram of the current oscillations which occur in the two circuits will be as shown in Fig. 254, the upper diagram representing the oscillations in the primary circuit until the spark is quenched at

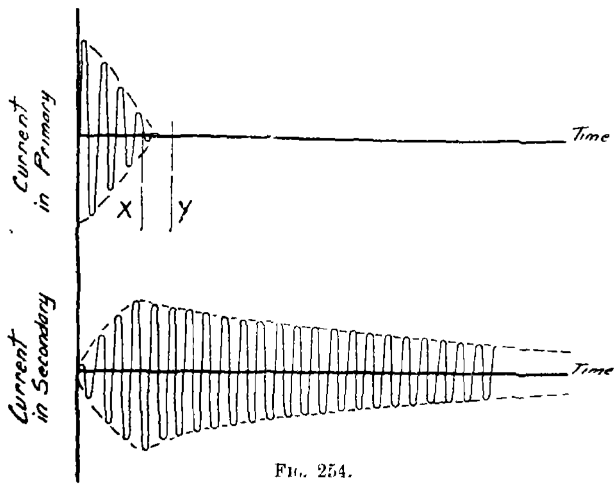


FIG. 254.

the moment X, and the lower diagram those in the secondary circuit.

1215. A spark having these characteristics is known as a **Quenched Spark,** and the result of coupling the two circuits together under these conditions is the production of a single wave, because as soon as the spark is quenched, which occurs after the first three or four oscillations, **the aerial circuit is free to oscillate to its own natural frequency.**

THE FIXED SPARK DISCHARGER

1216. The simplest form of persistent spark-gap consists of two spheres of metal to which connections are brought from the oscillatory circuit. These spheres are usually mounted on insulating pillars and their distance apart is adjustable. They rely almost entirely upon the cooling effect of the surrounding air for quenching any tendency to arc. The currents of air produced by the

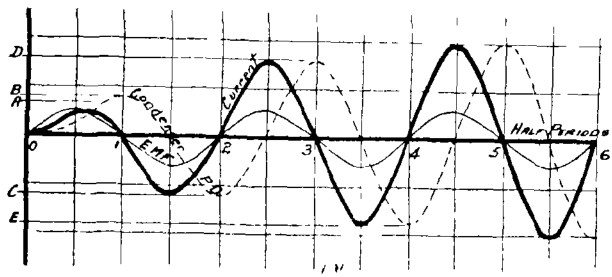


FIG. 255.

heat of the spark, however, are not sufficient to quench any serious tendency to arc, so that they can only be usefully employed when the spark frequency is very low, except when an induction coil is used for energising the oscillatory circuit. In this case the brief pause which takes place after a spark has occurred and before the next impulse commences, as explained in paragraph 1201, enables a simple gap of this description to deal with a comparatively rapid rate of sparking.

1217. In any case, however, it is essential that the length of the spark be carefully adjusted. The reason for this will be evident if we refer to the resonance curves

which we explained in paragraphs 1085 to 1091, and which are illustrated again in Fig. 255.

1218. The condenser PD, which is also the voltage across the spark-gap, rises at each half cycle to a higher and higher value, which approaches, but never reaches, a limit, until after the fifth half cycle the successive peaks, for all practical purposes, can be considered uniform.

1219. Examining the high-frequency circuit shown in Fig. 256, it will be seen that the spark-gap is connected across the condenser (the very small inductance of the Jigger-Primary being negligible so far as the low-frequency charging current is concerned). As soon as a spark occurs, therefore, the condenser can be considered as being short circuited through the gap, but until a spark occurs, **the voltage across the condenser will be also the voltage across the spark-gap.**

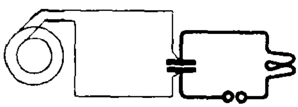


FIG. 256.

1220. Now the voltage at which a given spark-gap breaks down depends upon the length of the air-gap: we can therefore adjust the gap to spark at any given point on the voltage curve.

1221. Let us suppose that the length of the gap is such that it breaks down at a voltage represented by the height of the line A in Fig. 255. In this case, it is evident that the spark would occur just before the condenser PD has reached its maximum value **and also before the current flowing from the generator to the condenser has reached zero.** This current, which would otherwise have completed the charging of the condenser will therefore follow up the discharge across the gap,

and may thereby maintain an arc for a sufficiently long period to establish thoroughly a conductive bridge of vapour, which the cooling effect of the air would be unable to disperse in time for the next charging impulse.

1222. If, on the other hand, the gap is so set as to

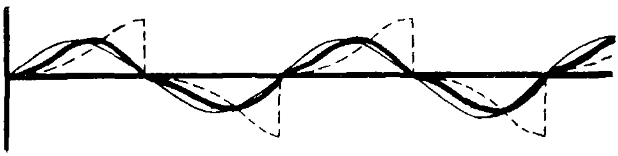


FIG. 257

break down at the voltage represented by the height of the line B in Fig. 255, then the spark will occur just at the moment when the condenser PD is at its maximum and when the current flowing from the

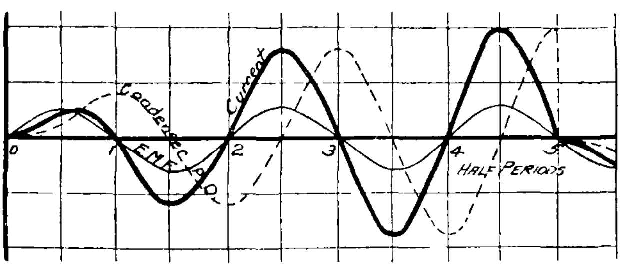


FIG. 258.

generator is zero. The curve showing the condenser PD and the current from the generator will then be as shown in Fig. 257, the discharge of the condenser being shown as a straight line bringing the condenser PD to zero at the end of each half period. Actually, of course, the discharge is oscillating and the condenser voltage rises

and falls on either side of zero many times before all the energy has been taken from the circuit, but, as we have already shown, the discharge is all over in an extremely short space of time compared with the time period of the alternator.

1223. It is also evident that the spark-gap can be set to break down at any of the voltages represented respectively by the heights of the lines C, D, E, and F. In any of which cases the spark would occur at a moment when there is no current flowing from the generator.

Fig. 258 shows the curve representing the condenser PD if the spark-gap be set so as to break down at the voltage D.

1224. As already explained, the cooling effect of this type of gap is not very good, and for this reason the spark frequency, for which it can be successfully employed, is limited. In practice it is found that it can deal with spark frequencies up to about 60 per second without serious tendency to arc, provided the size of the electrodes is suitable for the power they have to deal with, and that they are carefully set to spark at the right moment.

THE DISC DISCHARGER

1225. Perhaps the best form of discharger yet devised is the Disc Discharger. This consists of a number of studs, or spokes, A projecting from the metal rim B of an insulated wheel C, known as the "disc electrode," as shown in Fig. 259. This wheel is revolved at a high speed by mounting it on the shaft of a small motor or on the shaft of the alternator which is supplying the power to the oscillatory circuit.

On some convenient frame two "fixed electrodes"

D) are mounted, at a suitable angle, in such a way that their points come exactly opposite any convenient pair of studs on the rotating disc at the same moment. If the studs on the rotating disc are equally spaced, and if the two fixed electrodes are thus correctly distanced, it follows that at regular intervals during a complete revolution of the disc, the fixed electrode points will come opposite two of the disc electrode points.

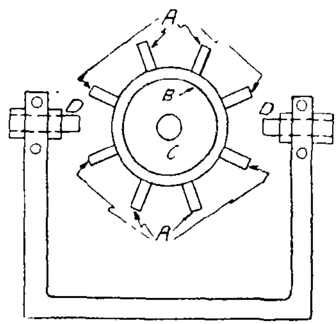


FIG. 259.

1226. If, when in this position the length of the fixed electrodes be adjusted so that they nearly, but not quite, touch the disc studs, then it is evident that while the disc is revolving, the length of the gap between one fixed electrode and the studs will be continually varying from practically nothing to half the distance between the two adjoining studs on the disc electrode. The application of such a discharger to an oscillatory circuit is as follows.

1227. Two leads are brought from the oscillatory circuit and connected one to each of the fixed electrodes, as shown diagrammatically in Fig. 260.

1228. When the disc is in the position shown in Fig. 259, the total air-gap between the two fixed electrodes is too big for the voltage of the charging generator to break down. Therefore the current generated by the dynamo will flow into the condenser and charge it up. This charging process will continue until the studs of

the revolving disc have approached the fixed electrodes sufficiently to allow the condenser to discharge across the reduced air-gap and through the oscillatory circuit. If, for any reason, the current is still flowing from the generator at the moment the discharge takes place, the arc which forms at the electrode as a result of this current is automatically drawn out by the rotation of the disc (due to the increasing distance between the fixed electrodes and the rotating studs), and the draught

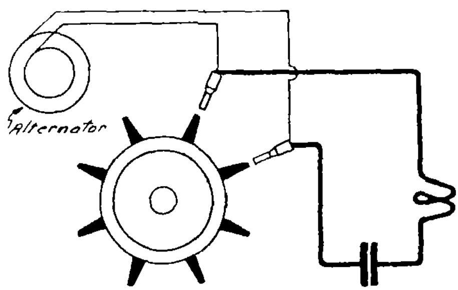


FIG. 260.

of air created by the rotating disc completely destroys the conductive bridge of vapour.

1229. Thus it will be seen that with a disc discharger any arc which forms at the electrodes due to current from the generator flowing through the gap, is broken up by the combined effect of the elongation of the arc and the *current of air generated by the rotating disc.*

1230. In some cases the disc electrode is fitted with fan blades for the purpose of increasing the draught of air, but this is unnecessary as we shall show, **if the approach of the electrodes is arranged to synchronise with the alternations of the generator.**

1231. Although this destruction of the arc will allow the condenser to be charged again before the disc studs once more approach the fixed electrodes, yet it is not entirely satisfactory, because even if an arc is formed for a short time, current will be flowing from the generator through the spark-gap without doing any useful work, thus representing so much wasted energy. Obviously, therefore, if we can arrange that at the moment when

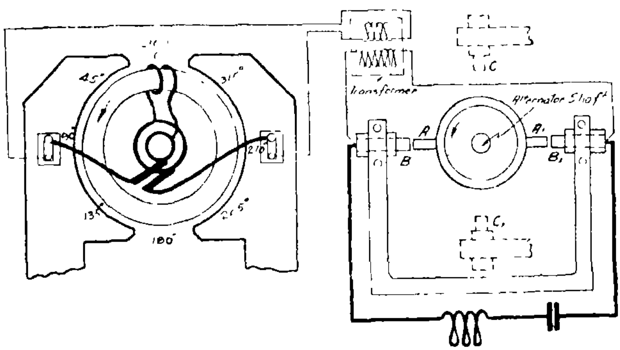


FIG. 261.

the discharge takes place no current, other than that discharged from the condenser, can flow through the spark-gap, we shall save all this wasted energy.

With a disc discharger these conditions can be obtained in a very simple way.

1232. For simplicity of explanation, let us imagine a two-pole alternator as shown in Fig. 261 with a single coil armature, and on the shaft of this alternator let us mount a disc with two studs A, A_1 fixed radially into its periphery exactly opposite each other as shown. In this diagram we have shown the disc and the alternator side by side to avoid confusion of lines,

but it should be understood that the disc is mounted on the shaft of the armature, and therefore rotates with the armature.

1233. Now, under these conditions, the studs on the disc will always bear the same relation to the position of the armature coil. If, then, we place two fixed studs B and B_1 in such a position that they come opposite the two rotating studs A and A_1 when the armature

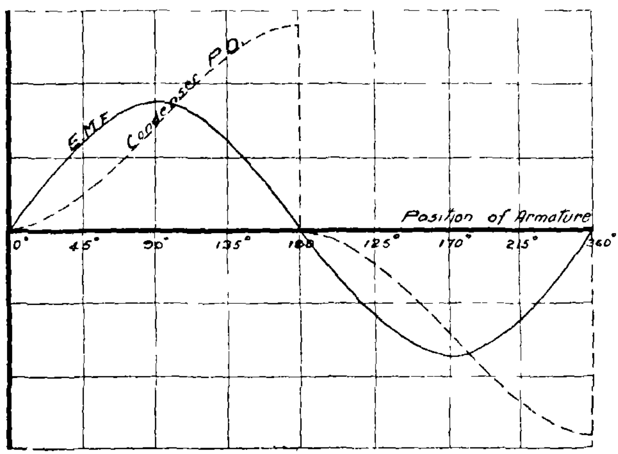


FIG. 262.

coil is in the position shown, *i.e.* at 0 or 360°, it is evident that whenever the armature coil is in this position the rotating studs will be opposite the fixed studs, and also, whenever the armature coil is at 180° the rotating studs will again be opposite the fixed studs.

1234. Fig. 262 shows the values of the alternator E.M.F. at different positions of the armature coil, so that if the position of the fixed studs relatively to the rotating studs be adjusted to the position shown in Fig. 261, when

the position of the armature coil relatively to the field magnets is also as shown in the same diagram, it is evident that the fixed and rotating studs will come together whenever the E.M.F. of the dynamo falls to zero, and therefore also when the condenser PD reaches its maximum. It is also evident that by moving the fixed studs to different positions between B and C (always keeping them opposite each other) we can arrange that the fixed and rotating studs come together at any desired point on the E.M.F. curve shown in Fig. 262. Thus, if they be moved to the positions C, C_1, the studs will always come together when the E.M.F. of the **alternator** is at its maximum.

1235. It will be readily seen that if we adjust the relative position of the electrodes so that they come **within sparking distance** at the moment when the condenser PD is at its maximum, this moment will also coincide with the time when the current flowing into the condenser is zero.

1236. In practice it is found that the relative position of the fixed and rotating studs can most conveniently be made by leaving the disc in a definite position on the alternator shaft and moving the fixed electrodes until they occupy the correct relative positions. With this arrangement it is possible to "set" the disc while the alternator is revolving at full speed, when it is easy to detect the best position from the sound and appearance of the spark.

It is very easy to see how this arrangement can be adapted to suit multipole alternators.

1237. In the case of a four-pole machine, for instance, as shown in Fig. 263, each revolution of the armature will produce four half-periods, and therefore the conditions

will be the same as in the case already described **if we mount four studs on the rim of the disc** as shown, because the studs of the disc will then come opposite the fixed electrodes four times during every revolution. **The number of studs on the disc should therefore always be equal to the number of poles in the alternator.**

1238. When a disc discharger is mounted in this way, *i.e.* so that the relative positions of electrodes always bear a definite relation to the relative positions of the armature windings and poles, it is known as a **Synchronous Disc Discharger,** and the spark frequency is then twice the frequency of the alternator, because we get a spark at every half-period.

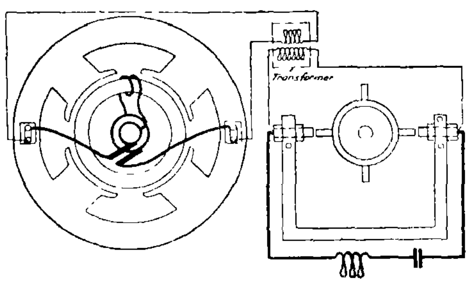


FIG. 263.

1239. The disc discharger is used as a rule for the production of persistent sparks, and its diameter, number of studs, and distance between studs is designed to suit the particular circuits for which it is required. But the amount of quenching effect which is obtained is very largely due to the peripheral speed of the disc electrode, because not only does the windage increase with the peripheral speed, but also the rate at which the spark is drawn out or elongated.

1240. Thus by increasing the peripheral speed of the disc, by increasing its diameter, and by increasing the windage produced at a given speed, any required degree of quenching can be obtained with a disc discharger.

THE "QUENCHED" SPARK-GAP

1241. We have already explained that quenching is simply a matter of cooling the spark rapidly enough.

We have shown how this can be accomplished in a disc discharger, by increasing the diameter of the rotary disc.

1242. A simpler way, however, presents itself, and one most commonly adopted, by making use of the property metals have of conducting heat. By dividing a spark-gap up into a sufficient number of very short gaps in series with one another, and arranging that the electrodes have ample section of metal for conducting the heat away from the spark very rapidly, and that they have plenty of surface exposed to the surrounding air for radiating the heat, any desired degree of quenching can be obtained.

1243. The electrodes of a quenched spark-gap are usually made of copper, which is one of the best conductors of heat, and consist of discs shaped in such a way that they can be piled one on top of another to form a complete discharger.

Mica is inserted between each electrode in such a way that it leaves a rim of metal to form the sparking surface on each electrode separated from the similar rim on the adjoining electrode by only a thin film of air; thus making the spark-gap as a whole self-supporting.

1244. Fig. 264 shows a sectional view of one of the

copper electrodes, and Fig. 265 shows several of these electrodes mounted together to form a complete discharger.

For large powers the size of the electrodes is increased

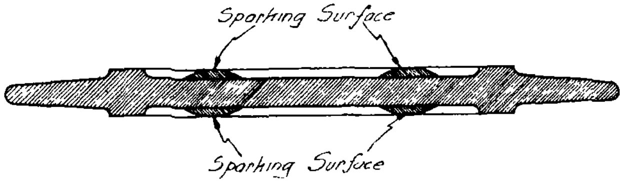


FIG. 264.

proportionally, and the cooling of the radiating surface is usually assisted by fans and other artificial means.

1245. For the satisfactory operation of this type of discharger it is essential that the sparking between elec-

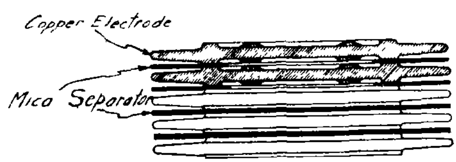


FIG. 265.

trodes is not confined to a particular spot, which would occur if the sparking surfaces were in the slightest degree uneven.

To avoid this the sparking surfaces must be kept highly polished and should frequently be repolished after use.

OSCILLATION VALVES

1246. The conduction of electricity through a vacuum, or rarefied gas, gives rise to phenomena which can be usefully employed in the art of Wireless Telegraphy. These phenomena can only be explained by the electron theory of matter which in principle is quite simple and easy to understand, provided we do not endeavour to develop the theory beyond what is necessary to explain the general principles underlying the action of the vacuum valve and the methods commonly used in adapting it to Wireless Telegraphy.

In this book we shall not attempt to go beyond the point necessary to give the student a simple working idea of the apparatus at present in commercial use.

The Electron Theory

1247. An Electron can be regarded as the smallest element of electricity and is of negative polarity. Its magnitude is approximately 10^{-19} coulomb.

1248. Each atom of any particular element consists of a cluster of some thousands of electrons, the exact number and arrangement being definite for any particular element. If by any chance one or more electrons are attached, or detached, from any atom, the latter

displays the same properties as an electrically charged body.

1249. In the case of electrons being **detached,** the atom becomes what is known as a "**positive ion,**" and will then produce the phenomena associated with a positively charged body. If, on the other hand, extra electrons become attached to the atom, it produces the phenomena associated with a negatively charged body, and is then known as a "**negative ion.**"

1250. Thus it will be seen that the terms positive ion and negative ion when applied to an atom simply imply that it is charged with electricity. The quantity of electricity with which it is charged depends entirely upon the number of electrons which have been detached from, or added to, the original atom.

1251. If an electron, or ion, be carried from one point to another, it produces the same results, and can therefore *be regarded as an electric current flowing between* those two points. Therefore if 10^{19} electrons (representing one coulomb, *vide* paragraph 1247) be carried from one point to another in one second, they represent a current of one ampere flowing between the two points. Whether these electrons are carried in the form of actual *electrons, positive ions* or *negative ions*, makes no difference except as regards the direction of the current.

The Fleming Valve

1252. If a metal wire or plate be placed in a vacuum and heated so that it becomes **incandescent,** the electrons, of which the particles of metal are formed, become, so to speak, loosened, and more or less free to move about.

1253. If two metal plates are placed in a vacuum, one

of which is rendered incandescent, and if an E M F is applied across the two plates **in such a way that the cold plate is positively charged,** a number of electrons will be attracted to the cold plate Thus the space between the two plates becomes conductive but **only in one direction,** because since the electrons are negative and are liberated from the hot plate only negative electricity can pass from the hot plate to the cold plate, which, in effect, is the same thing as saying that positive electricity flows from the cold plate to the hot plate

1254 This at first sight appears contradictory, because if we imagine electrons as particles of electricity, it is difficult to understand why the flow of these particles from the hot plate to the cold should be considered as causing a positive current to flow from the cold plate to the hot plate It must be remembered, however, that it is not necessarily a fact that the current flowing from, say, a primary cell flows from the positive terminal to the negative terminal, although this theory has been accepted for many years, long before the electron theory was evolved It will not upset any of the explanations previously given of electrical phenomena if we assume that the current in an electrical circuit flows from the negative terminal to the positive terminal, and this theory fits in much better with the electron theory if we wish to maintain the mental picture of electrons as real particles of electricity

1255 Whichever point of view is taken is immaterial however, to the phenomena we are about to discuss, and for the sake of uniformity we will, throughout the explanation, assume that the direction of the current produced is opposite to the direction of the flow of negative electrons in that part of the circuit

1256. An illustration of the Fleming Valve is shown in Fig. 266. It consists of a metal or carbon filament F, which can be rendered incandescent by passing a current through it, surrounded by a metal plate or cylinder S, usually cal'ed the "Sheath." These two electrodes, namely, the filament and the sheath, are enclosed in a glass bulb like an electric light bulb which is exhausted of all air, thus forming a vacuum inside the bulb.

1257. If, then, the filament be rendered incandescent, electrons will be liberated from its surface, and since these

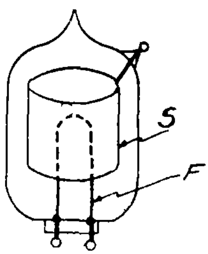


FIG. 266.

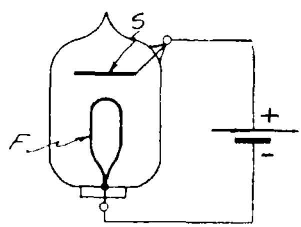


FIG. 267

electrons are negative, they can be attracted to the cold plate by connecting the positive side of a battery to the cold plate and the negative side of the battery to the filament, as shown in Fig. 267, with the result that a current will flow through the circuit so long as the temperature of the filament is maintained.

1258. In this diagram, for the sake of simplicity, we have left out the filament battery, *simply illustrating the* filament as a plain loop of wire F. The sheath is shown as a straight line S, and this plan will be adopted in many of the following diagrams.

Now under these conditions the space between the

filament and the sheath can be regarded as a conductor of electricity, but with several peculiarities.

1259. In the first place, it will only conduct electricity in one direction for reasons explained in paragraph 1253.

1260. In the second place, **it will only allow a limited amount of current to flow** through the circuit in that direction. The reason for this is that the number of electrons per second liberated from the filament is limited, so that no matter what voltage is applied between the filament and the sheath only this quantity of current can flow. The number of electrons liberated depends upon the size of the filament and the temperature to which it is heated; so for a given filament the quantity of current which can be carried through the valve depends upon the temperature or degree of incandescence to which the filament is heated.

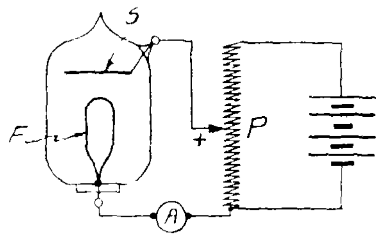


FIG. 268

1261. In the third place, the current which flows through the valve does not follow Ohm's Law, that is to say, the current is not proportional to the voltage applied across the valve.

If we place a measuring instrument "A" in the circuit, as shown in Fig. 268, and by means of a potentiometer P (*vide* Part I. paragraph 453) gradually vary the voltage applied between the filament and the sheath and plot the current readings as ordinates and the voltage readings as abscissae, the curve will take the form shown in Fig. 269. It will be seen that up to the voltage A the

rise in the current for a given increase in the voltage is very small, while beyond this point a very small increase in the voltage between A and B produces a very large increase in the current flowing through the valve. After the point B, however, there is no further increase in the

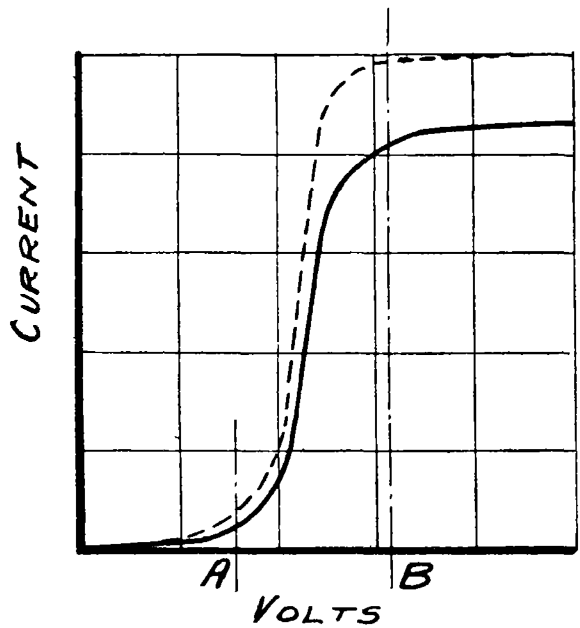


FIG. 269.

current for reasons explained in paragraph 1260. If the temperature of the filament be increased, then the maximum amount of current which can flow through the valve will be increased, and the current curve will take much the same form, but rising to a greater height, as shown by the dotted line in the same figure.

1262. A point worthy of notice regarding these curves is that in both cases the current reaches its maximum value at approximately the same voltage point, therefore the rate of increase in the current between the moments A and B is greater the higher the temperature of the filament.

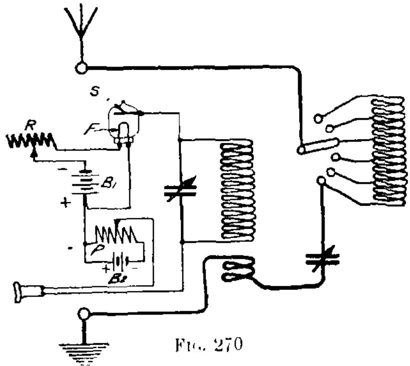


Fig. 270

1263. Now the characteristics of this curve are very similar to those of the carborundum curve shown in Fig. 79, Part I., and the valve in this form can therefore be used as a detector of feeble electrical oscillations by connecting it to circuits similar to those used with a crystal which were fully described in Part I.

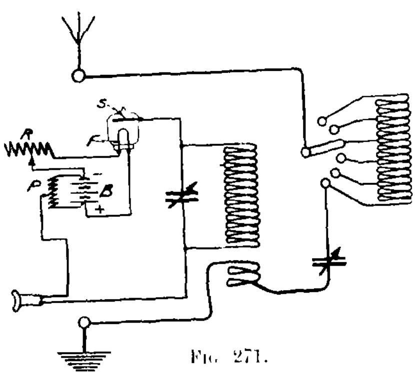


Fig. 271.

1264. In Figs. 270 and 271 we have illustrated the connections of a simple tuned *Receiver* using *the valve as a detector*, the oscillatory circuits being identical with

those of the crystal receiver which was illustrated in Fig. 77, Part I.

In Fig. 270, a four-volt battery B_1 is used to heat the filament, and an adjustable resistance R is provided for regulating the brilliancy of the filament. A separate battery B_2 and potentiometer P are connected in series with the telephones across the valve, *i.e.* between the filament and the sheath by means of which the voltage across the valve can be brought to the point A in Fig. 269, at which point the oscillatory currents will be rectified most efficiently.

It is not necessary, however, to use two batteries, because the potentiometer can be connected across the filament battery, as shown in Fig. 271

1265. The sensitiveness of a Fleming Valve used in this way is about the same as that of carborundum crystal, and for many years the Fleming Valve was used as the standard form of detector on a large number of commercial stations.

It was, however, later superseded by the crystal detector on account of the advantage the latter has in not requiring a battery capable of giving a current of perhaps one or two amperes which is necessary for heating the filament of the valve.

1266. Recent discoveries, however, have enabled the Fleming Valve in a modified form to be used not only as a powerful magnifier, but also as a generator of high frequency continuous oscillations, which can be used for the production of continuous waves, the advantages of which are fully explained in later paragraphs.

The Magnifying Valve

1267. If a frame of metal gauze, called a "grid," be interposed between, and entirely insulated from, both the filament and the sheath of the Fleming Valve as shown by G in Fig. 272, it is found that **normally** practically no electrons will travel from the filament to the sheath, no matter to what degree the latter be charged positively, thus making the valve a non-conductor of electricity. The reason for this is that a great many of the electrons, which are attracted from the incandescent filament when the sheath is artificially charged to a positive potential, fall on the wires of the grid, thus charging the grid to a negative potential. This negative potential on the wires of the grid effectively shields the filament from the static field of any positive charge given to the outer sheath. The result is that no electrons will be attracted from the filament beyond those necessary to charge the grid negatively, and therefore no current can flow from the outer sheath to the filament.

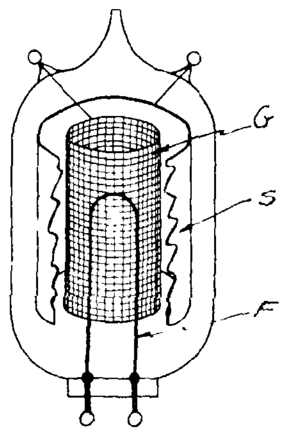


Fig. 272.

1268. In Fig. 273 we have illustrated this condition diagrammatically, where F represents the incandescent filament, S the outer sheath, and G the grid. We have shown a battery B by means of which a positive charge of say 100 volts is given to the outer sheath. No

current can flow through the valve, however, on account of the shielding effect of the grid G, which becomes negatively charged by the electrons attracted in the first instance by the outer sheath, some of which fall on to the grid on their way.

1269. The magnitude of the negative charge on the grid, which is sufficient to shield from the filament even a very strong positive charge on the outer sheath, depends upon the size of the mesh and the size of the wire forming the grid, also upon the distance from the grid to the filament, and from the grid to the outer sheath, and will therefore vary enormously with different designs of valve.

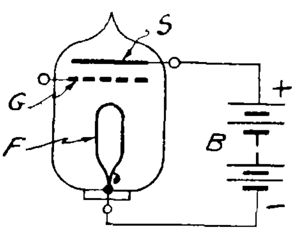


FIG. 273.

1270. With a suitably constructed valve it is found that a small negative charge of perhaps ten volts on the grid is sufficient to shield a positive charge of several hundred volts on the outer sheath. If the negative potential on the grid be reduced, then a certain number of electrons can pass through the grid, and if its potential be reversed by applying a positive E.M.F. to it from an outside source, then its shielding effect is entirely neutralised and the electrons can pass freely from the filament to the sheath through the meshes of the grid, or, in other words, the valve becomes conductive, and a current can pass from the battery B through the circuit.

1271. Now the amount of energy necessary to vary the potential of the grid is extremely small, because when an electro-motive force is applied to anything, no energy

is expended until a displacement of electricity has been effected, and since the capacity of the grid is negligible, the energy expended in changing its potential is also negligible.

1272. **Thus it will be seen that by using a very small amount of energy to reverse the potential on the grid, we can control a comparatively large amount of energy in the outer sheath circuit.**

This, briefly, is the principle underlying the use of the vacuum valve as a powerful relay or magnifier.

The Space Charge

1273. In paragraph 1270 we stated that if the negative potential on the grid were reversed its shielding effect is neutralised, and the electrons could then pass freely from the filament to the sheath. There is another factor, however, which we have not yet mentioned, namely, the effect of one electron on another.

When the grid potential is reduced the space between the filament and the sheath becomes filled with a cloud of negative electrons which are on their way to the positively charged sheath, and those electrons nearest the sheath at any moment are not only being attracted by the sheath but are also being **repelled** towards the sheath by the negative electrons behind them. Those electrons which are farther away from the sheath, however, have not only got fewer electrons behind them to push them towards the sheath, but they have also electrons in front of them which are tending to push them back towards the filament. This effect is known as **the space charge,** and its result is to choke back the stream of electrons

attracted by the positively charged sheath from the incandescent filament.

1274. Now this space charge can be neutralised by charging the grid to a positive potential, so that if after we have reduced the negative charge on the grid to zero we start charging it to a positive potential, the current flowing through the valve from the sheath to the filament will continue to increase until the stage is reached, known as the saturation point, when the filament is giving off the maximum number of electrons (*vide* paragraph 1260).

1275. This effect can be illustrated in a curve diagram by plotting the values of the **grid potential** along the horizontal axis and the values of the **current which will flow in the outer sheath circuit** as ordinates, as shown in Fig. 274.

1276. The actual values of the current which will flow in the sheath circuit for different values of grid potential will, as we have already mentioned, vary according to the size of the mesh and size of wire of grid, also upon the distances between filament and grid, and between outer sheath and grid, and the potential applied between the outer sheath and the filament.

The curve in Fig. 274 illustrates the case of a typical valve of comparatively small dimensions, such as would be used for receiving purposes, with a battery of 100 volts applied between the sheath and the filament.

1277. In Fig. 275 we have shown diagrammatically the circuit from which these results were obtained. The outer sheath S of the valve is connected through a micro-amperemeter A to the positive terminal of a 100-volt battery B, the negative terminal of which is connected to the incandescent filament F. The grid G of the

valve is connected through a potentiometer P to the incandescent filament F. It will be noticed that the

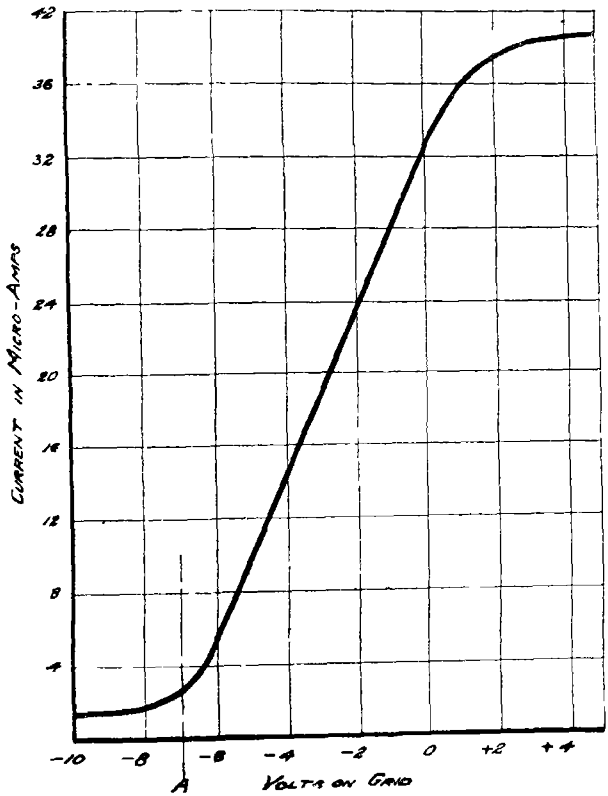


FIG. 274.

potentiometer P is so connected that the E.M.F. between the grid and the filament can be varied from a negative value of say 10 volts when the slider is in the position X to a positive value of 10 volts when the slider is in the

position Y, thus allowing the grid potential to be varied to any desired value between these two limits.

1278. Now this is not in any sense a circuit on which signals can be received, but it is merely a circuit designed to show how the characteristic curves of the valve are obtained, and the student is advised to master these connections thoroughly and the meaning of the curve shown in Fig. 274 before attempting to follow the methods of applying this type of valve to receiving or transmitting circuits.

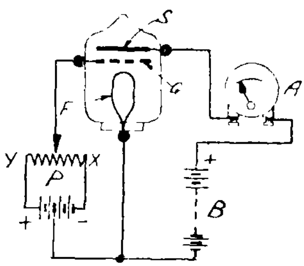


FIG. 275.

1279. In the other experiments described in this book, we have illustrated by means of curves the relation between the E.M.F. and flow of current in the same circuit. *This curve, however, illustrates the relation between the E.M.F. in one circuit and the current which flows in another circuit.*

1280. Looking at Fig. 275, it will be seen that the E.M.F. which is obtained from the potentiometer P is applied to the circuit shown on the left-hand side of the valve, consisting of **the grid G, the potentiometer P, and the filament F,** and it is these values which are plotted along the horizontal axis in Fig. 274. The current which is measured by the instrument A, however, is that which flows in the circuit shown on the right-hand side of the valve, consisting of **the sheath S, the instrument A, the battery B, and the filament F,** and it is these values of current which are plotted as ordinates in Fig. 274.

1281. To distinguish between the two circuits we shall in future term the former the **Grid Circuit**, and the latter the **Sheath Circuit.**

SIMPLE METHODS OF APPLYING VALVE TO RECEIVING CIRCUITS

1282. If the student has thoroughly understood the conditions necessary to produce a sound in a telephone receiver, and the manner in which the rectifying properties of carborundum and other crystals can be used to obtain these conditions in a receiver, he will have no difficulty in following the first and simplest method of applying this type of valve for the same purpose.

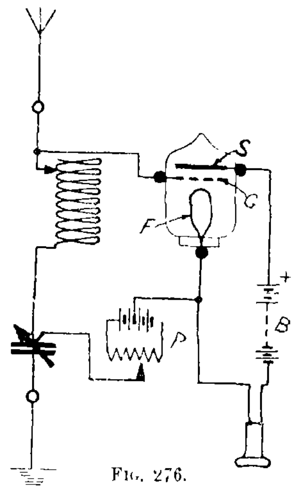


FIG. 276.

1283. The distribution along an aerial of the E.M.F. induced by the incoming signals is exactly the same as that induced by a transmitter, and described in Part I., paragraphs 632 to 664.

1284. For a single circuit receiver, therefore, we should connect the grid to one end of the aerial tuning inductance and the filament to the other end, as shown in Fig. 276, because we wish to control the current in the sheath circuit by the received oscillation. Also, we should connect the telephones in the sheath circuit in series with a suitable battery.

1285. By means of the potentiometer P the initial voltage of the grid can then be adjusted, as in the case of a crystal detector, to the point A, where the bend occurs in the current curve illustrated in Fig. 274. Under these conditions it is evident that the oscillatory E.M.F. induced in the aerial by an incoming signal will *vary the potential of the grid* on either side of the point A, thus causing a simultaneous variation in the current flowing through the telephones connected in the sheath circuit.

1286. On account of the shape of the current curve, however, the average increase in the current due to the positive halves of *the received oscillations* is greater than the average decrease in the current due to the negative halves of the received oscillations, so that even though the frequency of the oscillations be hundreds of thousands per second, the telephone will respond to the average increase in the current passing through them.

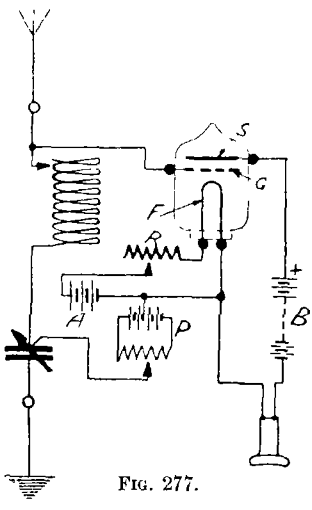


Fig. 277.

In Fig. 276, for the sake of simplicity, we have represented the filament as a loop of wire. In Fig. 277, however, we have shown the complete connections of the same receiver, where A is the battery supplying the current necessary to maintain the incandescence of the filament, and R is

the adjustable resistance for varying the brilliancy of the filament.

1287. For the same reasons as those described in Part I., paragraph 462, unless the received wave-length is very long compared with the length of the aerial, better results can be obtained by connecting the valve to the secondary circuit of a two-circuit receiver, as shown in Figs. 278 and 279, Fig. 278 showing the simplified diagram.

Now, apart from the fact that with this type of

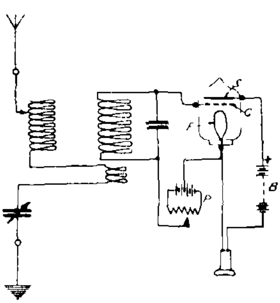


FIG. 278.

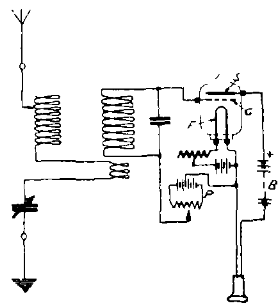


FIG. 279.

valve we can control a comparatively heavy current in the sheath circuit by simply causing the incoming signal to vary the potential of the grid, it has one great advantage over the other types of detector described in Part I. This advantage lies in the fact that practically no energy is expended by the received oscillations on the grid, because no current is caused to flow in the grid circuit, whereas in the case of any of the detectors described in Part I. the current which operates the telephones is supplied by the received

oscillations, with the result that these oscillations are more highly damped than in the receiver just described.

Reception of Weak Signals

1288. By examining carefully the curve illustrated in Fig. 274, it will be noticed that the bend at the point A is not a sharp angle, but is rounded off. If the received signals are strong enough the variation of the potential of the grid on either side of the initial voltage supplied by the potentiometer will cause a rectified current to flow in the sheath circuit. By rectified current we mean a current whose average value is greater than the normal value. If, however, the received signals are very weak the small variation of the E.M.F. on the grid will only cause an "oscillating" current to flow in the sheath circuit on account of the rounded bend in the curve. By oscillating current we mean a current which varies **equally** on either side of the normal value, and, therefore, whose average value, so far as the telephones are concerned, is zero.

1289. This point will be better understood by referring to the enlarged illustration of the bend of the curve shown in Fig. 280.

If the initial voltage of the grid be adjusted to the point A as before, *i.e.* to $-7{\cdot}5$ volts, then it will be seen from the curve that a steady current of 2 micro-amperes will flow through the telephones before any signals are received.

1290. Now let us suppose that the received oscillations cause a variation of the grid potential of $1{\cdot}5$ volts on either side of this value, that is to say from

–9 volts to –6 volts, then it will be seen from the curve that the positive half of the oscillation will cause an increase of 3 micro-amperes and the negative half a decrease of ·5 micro-ampere in the current flowing through the telephones, in which case the effective value of the current, so far as the telephones are concerned, will be 3 – ·5 = **2·5 micro-amperes.** On the other hand, if the received oscillations cause a variation of the grid potential of only ·25 volt on either side of the value A, that is to say from –7·75 volts to –7·25 volts, then it will be seen from the curve that the positive half of the oscillation will cause an increase of ·3 micro-ampere, and the negative half a decrease of ·3 micro-ampere, in which case the effective value of the current in the telephones will be **zero.** Thus it will be seen that although the weak signals have caused a perceptible change in the current flowing in the sheath circuit, the telephones cannot respond to this current on account of the fact that it is not rectified.

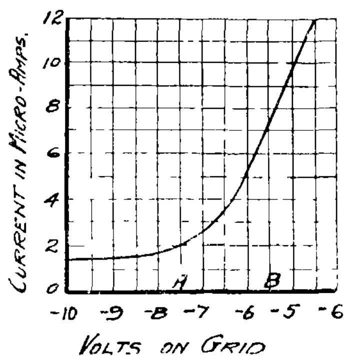


Fig. 280

1291. This difficulty can be overcome by replacing the telephones with an oscillatory circuit, called the "sheath oscillatory circuit," **in resonance with the frequency of the oscillatory currents thus produced.** Then the oscillating current in the sheath circuit will energise this oscillatory circuit, and the current flowing in the

latter can be rectified in the ordinary way with a carborundum crystal and made to operate the telephone receiver as shown in Figs. 281 and 282, Fig. 281 showing the simplified diagram without filament battery, and Fig. 282 showing the complete diagram.

1292. Under these conditions it will be seen that the valve can be used far more efficiently, because **since**

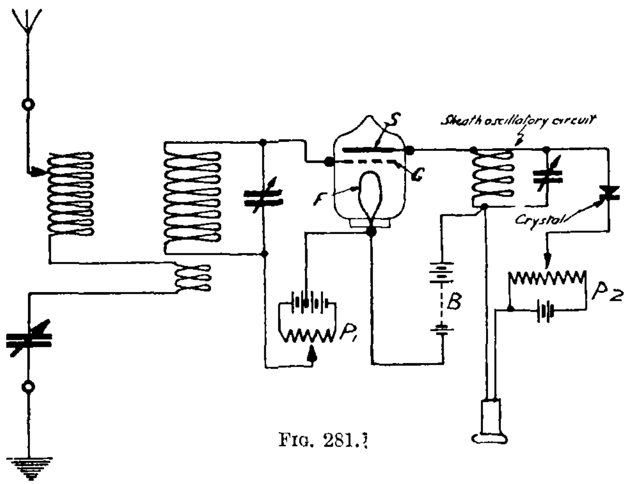


Fig. 281.

there is no longer any necessity to produce a rectified current in the sheath circuit, we can adjust the initial voltage of the grid to the point where a given variation in the grid potential caused by the received oscillations **will produce the greatest change** in the current flowing in the sheath circuit. Thus if we adjust the grid potential to the point B in Fig. 280, it will be seen that a variation in the grid potential of ·25 volt on either side of this value will cause an increase of about 1 and a decrease of about 1 micro-ampere to flow in the sheath

circuit, thus nearly quadrupling the energy available for rectifying by the carborundum.

Reaction Method of Applying Valves to Receiving Circuits

1293. We now come to the final and most efficient method of utilising the properties of the magnifying

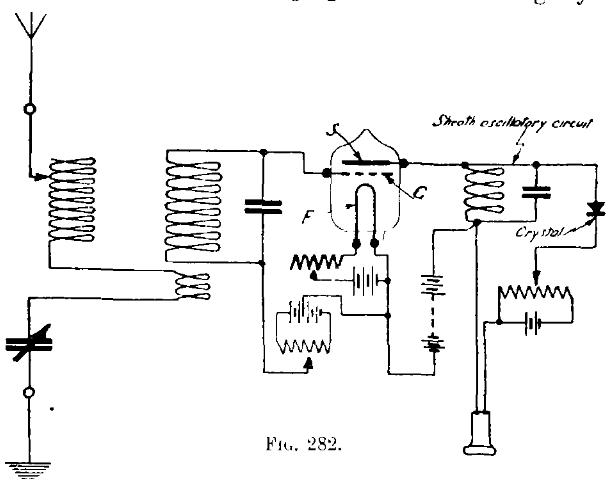


Fig. 282.

valve for the purposes of reception of spark signals. It is known as the reaction method.

The principle underlying its action is to utilise some of the energy liberated in the sheath circuit by the incoming oscillations to boost up or increase the persistency of the incoming oscillation.

1294. At first sight this appears to be rather like "robbing Peter to pay Paul," but it will be remembered that the energy in the sheath circuit is derived from an entirely different source from that which is controlling

it by the grid. Now the amount of energy liberated in the sheath circuit is, as we have shown, dependent upon the amplitude of the received oscillations. If, therefore, we utilise some of this energy to increase the amplitude of the received oscillations, this in turn will cause more energy to be liberated in the sheath circuit,

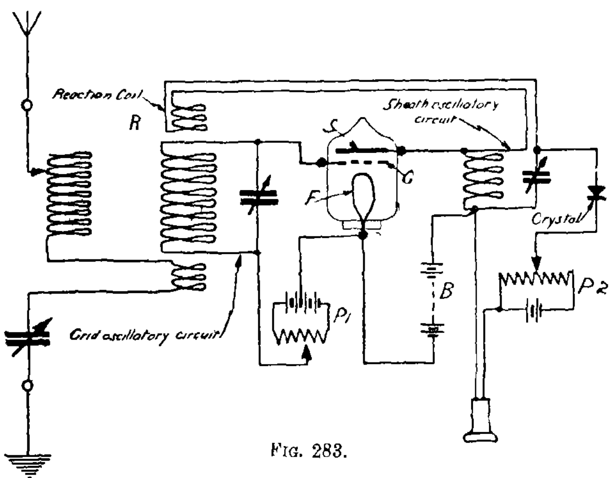


Fig. 283.

thus enormously increasing the magnifying effect of the valve.

1295. Fig. 283 illustrates diagrammatically how this is accomplished. It will be noticed that up to a certain point the connections of this receiver are identical with those of the receiver illustrated in Fig. 281, the only difference being that we have placed a portion R (known as the reaction coil) of the inductive winding of the sheath oscillatory circuit in such a position that any current flowing in this circuit will induce an E.M.F. in the grid oscillatory circuit.

1296. The frequency of the oscillations in the sheath oscillatory circuit is the same as the frequency of the incoming oscillations, and therefore also the same as the frequency of the grid oscillatory circuit so that any E.M.F. induced in the grid coil by the oscillatory current flowing through the reaction coil will add itself to that induced in the grid coil by the incoming oscillations.

1297. The amount of this extra E.M.F. induced in the grid coil by the reaction coil **can be controlled by adjusting the coupling between the two windings,** so by varying the value of this coupling we can get any desired degree of amplification (within limits) of the incoming oscillations.

Fig. 284.

1298. The effect of this on the received oscillations will be more readily understood by referring to Figs. 284, 285, and 286. Fig. 284 represents a group of received oscillations, such as might be produced in the grid coil by a single spark from a transmitter some distance off, assuming that the coupling between the reaction coil and the grid coil is zero.

1299. Owing to the loss of energy due to the resistance of the aerial and the resistance of the grid oscillatory circuit, these oscillations are highly damped and die out after a very few cycles. It follows, therefore, that the oscillations produced in the sheath circuit also die out in a very few cycles, because all the energy in that circuit is being

converted by the telephones into sound as fast as it is available.

1300. If now the reaction coil be brought nearer to the grid coil, so that the oscillations produced in the sheath circuit react on the grid coil, then the oscillations produced in the latter by a spark from the distant transmitter instead of dying down in a few cycles will be maintained for a considerable length of time, as shown in Fig. 285. Thus the effect of the reaction coil is the same as if the damping effect of the aerial and receiver circuits had been very much reduced. Also the amount of energy in the sheath circuit now available for the telephones will be increased in proportion to the length or persistency of the group of oscillations.

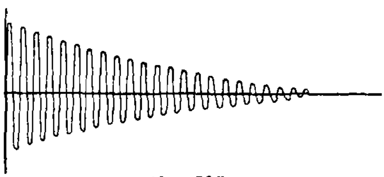


FIG. 285.

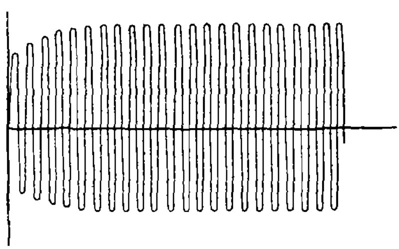


FIG. 286.

1301. From this it will be quite evident that if the coupling between the reaction coil and the sheath coil be still further increased, the point will be reached when the received oscillations instead of dying down will actually increase in amplitude, as shown in Fig. 286, and the circuits will then continue to oscillate for ever, that is, of course, so long as the

other conditions, such as filament brilliancy, battery potentials, etc., are maintained.

1302. When the circuits are adjusted to obtain these conditions, **the valve is said to be oscillating**, and the uses to which it can then be put will be described later. For the present, however, we shall discuss only the conditions which are most suitable for the reception of spark signals.

1303. In Part I., paragraphs 533 to 536, we showed how the sound produced in the telephones of the receiver depended upon interruptions in the current passing through them. That is to say, a steady current, such as would be produced if a continuous stream of oscillations were rectified, would not produce a sound in the telephones beyond the first "click" when the current commenced to flow. Therefore, if the coupling between the reaction coil and the grid coil of the receiver just described be adjusted so that the first group of oscillations received starts the valve oscillating, the signals transmitted by the sending station would be indistinguishable in the telephones. On the other hand, the strength of the click produced in the telephones by a group of oscillations of given amplitude will increase more or less in proportion to the length or duration of that group. Obviously, therefore, the most sensitive adjustment of coupling between the reaction coil and the grid coil will be that which maintains the received oscillations just sufficiently to allow them to die out just before the next group is received. Under these conditions each spark of the transmitter will liberate the maximum amount of energy in the sheath circuit while keeping the effect of each spark distinct.

Reception of Continuous Waves

1304. So far we have only dealt with the various problems concerned in the transmission and reception of damped oscillations, or, as they are more usually termed, "spark signals."

Recent developments and improvements in the production, and more particularly in the reception of continuous or undamped oscillations, have given this method of wireless communication important advantages over the earlier methods employed, more especially in the high selectivity of wave-length, which is easily obtained.

1305. We have already made it clear that the note of the received signals corresponds with the number of groups of waves transmitted, that is to say, with the spark frequency of the transmitter, because each group of oscillations causes a change in the average value of the rectified current passing through the telephones. If each signal transmitted from the sending station consists of a single stream of undamped oscillations, these oscillations if received on any of the receivers yet described would produce no sound in the telephones beyond a single click at the commencement and finish of each signal, as the diaphragm of the telephone receiver is drawn nearer to and released from the telephone magnets.

1306. In other words, it is not sufficient to pass a rectified current through the telephones of long or short duration to enable an operator to read a Morse signal unless this rectified current is broken up into groups of a frequency capable of being detected by the human ear.

1307. The most obvious way of getting over this

difficulty is to break up the stream of oscillations at the receiving station. This could be accomplished by rapidly interrupting the telephone circuit by means of a buzzer. This method, however, has many disadvantages in practice, the chief of which is that the note of the received signal is entirely controlled at the receiving station, so that any electrical disturbances which affect the receiver circuits, whether they be atmospheric or signals from another station, will be reduced to exactly the same note in the telephones.

By the method known as the "Beat Reception" none of these disadvantages occur, and very high selectivity can be obtained.

"Interference" or "Beat" Reception

1308. The principle underlying Beat Reception is *the effect produced by adding together two alternating currents of different frequencies.*

1309. If two generators are both supplying current to a common circuit, the current flowing in that circuit will be the **sum** of the currents supplied by each generator, provided both currents are in the same direction. If the two currents are in the opposite direction, then the total current flowing in the circuit will be the **difference** between the two currents. From this it follows that **if two alternating currents, both having exactly the same frequency, and both in phase with one another,** as represented by the sine curves A and B in Fig. 287, be superimposed in the same circuit, the total current flowing through that circuit can be represented by a sine curve C, Fig. 287, whose ordinate at any moment is equal to the sum of the

ordinates of the two sine curves A and B. In Fig. 287, the two alternating currents are exactly in phase, and the total current flowing, as represented by the curve C, is obviously always greater than either of the two currents taken separately.

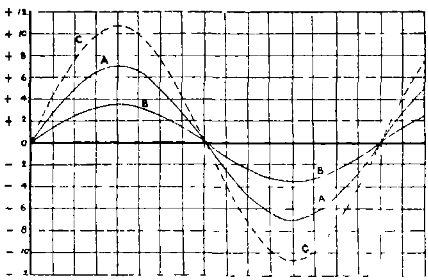


FIG. 287.

1310. **If the two superimposed currents are out of phase,** as shown in Figs. 288 and 289, then the total current will be very much smaller than before, because during a part of each cycle the two currents are in opposite directions. The greater the phase difference the lower the resultant current. The dotted line C again represents the total current flowing in the circuit, because it will be found that at any moment its ordinate is equal to the sum of the ordinates of the two curves A and B. For instance, at the moment X (Fig. 288), A = +3, and B = −3, therefore C = O, and at the moment Y, A = +6, B = +2, therefore C = 8.

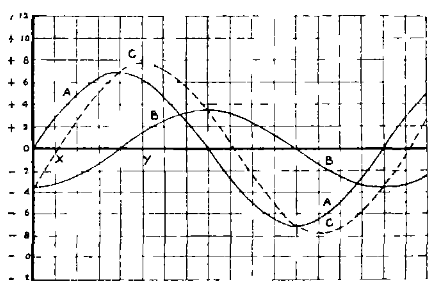


FIG. 288

1311. In Fig. 289 the two currents are 180° out of

phase, so the resulting current is always equal to the difference between the two currents.

Thus it will be seen that the resulting current will have a maximum amplitude when the two superimposed currents are in phase, and a minimum amplitude when the two superimposed currents are 180° out of phase.

1312. If now **two alternating currents, each having a different frequency,** be superimposed on one another, the resulting current can be found in exactly the same way, but in this case the resulting current will not have a constant amplitude as was the case when the two currents had the same frequency, **because their phase relation is continually changing.** The amplitude of the total current will

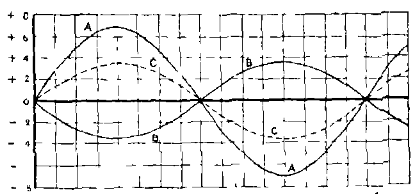


FIG. 289.

therefore continually increase and decrease as the two superimposed currents come in and out of phase with one another, as shown by the curves in Fig 290. In this diagram, to avoid confusion of lines, we have drawn each curve on a separate horizontal axis, but the vertical axes are the same in all three curves, thus the lower curve is drawn by the simple process of adding the instantaneous ordinates of the two upper curves, as before.

1313. These increases in the amplitude of the total current are known as "beats."

1314. The frequency of the alternations of the resultant current will be between the two frequencies of the superimposed currents, but **the frequency of the**

beats is equal to the difference between the frequencies of the superimposed alternating currents.

Thus, if the frequency of the alternating current A is 100 per second, and that of B 110 per second, then the frequency of the resulting current will be somewhere between 110 and 100 per second; but the frequency of the beats will be 110 - 100 = 10 per second. It is evident that the smaller the difference between

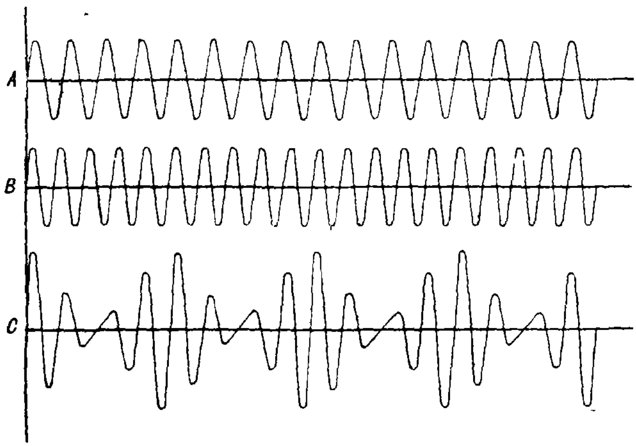


Fig. 290.

the frequencies of two superimposed alternating current, the lower the frequency of the beats.

1315. Now, if the amplitude of the two superimposed alternating currents be equal, as shown in Fig. 290, the amplitude of the resultant current will vary from a maximum value, equal to twice the superimposed currents when they are in phase, to a minimum value of zero when they are 180° out of phase. But if the amplitude of the two alternating currents be different,

as shown in Fig. 291, then the amplitude of the resultant current will vary from a maximum of the sum of the two superimposed alternating currents when they are in phase, to a minimum of the difference between the two alternating currents when they are 180° out of phase. The frequency of the beats, however, remains the same as before. The variation in the amplitude of the resultant current can be termed the amplitude of the beat.

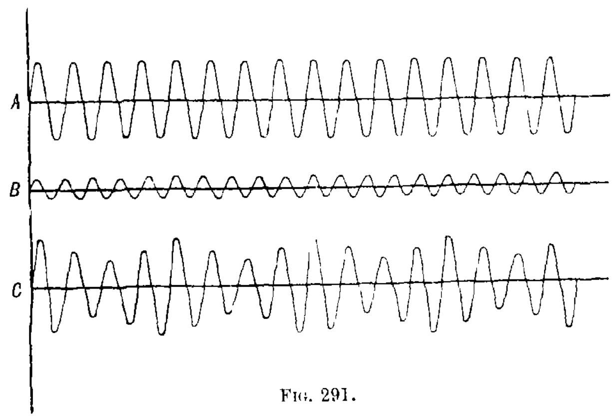


FIG. 291.

1316. Exactly the same results will be obtained if two high-frequency oscillating currents of different frequencies are superimposed on one another. The resulting current will also be a high-frequency oscillating current, but its amplitude will vary as the two currents come in and out of phase with one another. The frequency of the beats thus formed will be equal to the difference between the two frequencies.

Let us now see how this principle can be applied to

the problem of reading signals transmitted in the form of undamped oscillations, *i.e.* continuous waves.

1317. Taking the case of the simple form of valve receiver, illustrated in Fig. 276, a series of continuous oscillations received on the aerial, as shown by the upper curve in Fig. 292, will produce a rectified current in the sheath circuit as illustrated by the lower curve in Fig. 292, provided **the grid potential be adjusted to the rectifying point** as previously described, and the ampli-

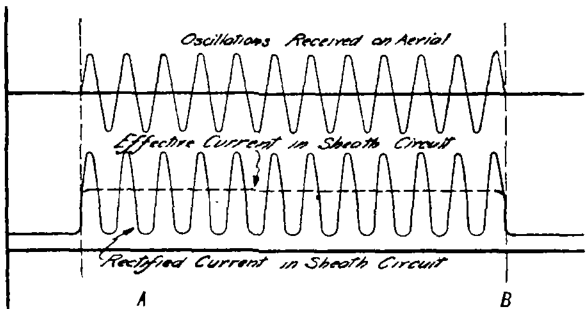


FIG. 292.

tude of the received oscillations is sufficient to get beyond the rounded bend of the sheath current curve, as explained in paragraph 1290.

1318. The telephones, however, will act as though a continuous current, corresponding to the dotted line in the lower part of Fig. 292, were passing through them (*vide* Part I., paragraph 525), and therefore, as already explained, will produce no sound beyond a single click at the moments A and B.

1319. Now, if by some artificial means, similar to that shown in Fig. 293, we create in the aerial a continuous stream of oscillations, quite apart from those received

from the transmitting station (*vide* Fig. 294, curve A), then the diaphragm of the telephone will be permanently deflected to a definite amount, so long as these oscillations are maintained, and once more no sound will be produced in the telephones. But when on top of this, continuous oscillations are received from the transmitting station (*vide* Fig. 294, curve B), then the amount of

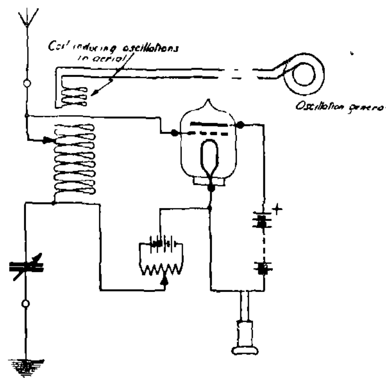


Fig. 293.

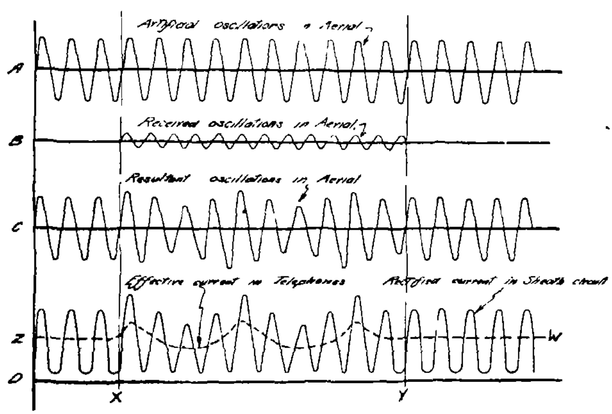


Fig. 294.

rectified current flowing through the telephones will be varied. If the frequency of the artificial oscillations be

adjusted so that it is slightly different to the frequency of the received oscillations, then the resultant oscillations will, as already explained, vary in amplitude, as shown by curve C, Fig. 294, giving beats of a definite frequency depending upon the difference between the frequencies of the artificial and received oscillations, with the result that the rectified current in the telephones, as shown by curve D in Fig. 294, will also vary in the same way.

1320. Now the frequency of the variation in this rectified current may be quite slow enough for the diaphragm of the telephone to follow, so that a musical note will be produced in the telephones so long as oscillations of the correct frequency are being received by the aerial. The pitch of this note can be varied quite independently of the transmitted signal, by varying the frequency of the artificial oscillations, but the important point to note is that for a given artificial frequency different received wave-lengths will give entirely different musical notes in the telephones.

1321. If the difference between the frequencies of the received and artificial oscillatory currents be small enough, the note produced in the telephones will be so low as to be inaudible to the human ear, and similarly, if this difference be great enough, the note produced will be too high to be audible, even if the diaphragm of the telephones is able to follow it.

1322. The highest audible note has a frequency of about 16,000 cycles per second, so that in order to produce any sound in the telephones by this method of reception, it is evident that the difference between the frequencies of the received and artificial oscillations must not exceed this limit.

Let us take an example. Suppose we wish to receive signals from a station transmitting undamped waves having a wave-length of 1000 metres; since the frequency of this wave-length is 300,000, it follows that the artificial oscillations must not have a greater frequency than 316,000, or a lower frequency than 284,000, as in either case the frequency of the beats would be greater than 16,000. If the frequency of the artificial oscillations be varied between these two extremes, starting at the lower limit, the note produced in the telephones by the received oscillations will vary from a very high pitched note when the frequency is, say, 284,000, to a very low note when the frequency has been increased to nearly 300,000 ; then if the artificial oscillations be increased in frequency still further, the sound in the telephones will become inaudible until the frequency has passed 300,000, when once more a very low note will be produced in the telephones, which will increase in pitch as the frequency of the artificial oscillations is increased, until once more it becomes too high to be audible after this frequency reaches 316,000.

1323. In the same way it will be found that if the frequency of the artificial oscillations be fixed at, say, 300,000 per second, then no received signals can be heard other than those whose wave-lengths lie between the approximate limits of 947 metres to 1053 metres.

1324. The extraordinary selectivity of this method of reception will be noticed not only from the fact that a variation of the transmitted wave of only five per cent per thousand on either side of the value for which the receiver is adjusted renders the signals inaudible. But also, even if the transmitted wave-lengths of two neighbouring stations both come within this limit, the smallest differ-

ence in the wave-length of the two stations will produce an entirely different note in the telephones of the receiving station.

1325. Thus, if a station A is transmitting on a wavelength of 1000 metres, and at the same time a station B is transmitting on 999 metres, and if a receiving station C had set his artificial oscillations at a frequency of, say, 300,500, then the signals of station A would produce a note frequency of 500 in his telephones, while those of station B would produce a note frequency of 200, enabling the operator to distinguish between them easily by ear.

Production of Undamped Oscillations by the Valve

1326. In order to receive continuous wave-signals by this method, some form of apparatus must be supplied for generating undamped high-frequency oscillations in the receiving aerial, and so far we have not discussed any method of producing undamped oscillations.

We have already described a form of valve receiver, in which high-frequency oscillations could be produced in the sheath circuit of the valve.

In paragraphs 1291 and 1292 we pointed out that a closed oscillatory circuit could be energised by causing the oscillatory current produced in the sheath circuit of a valve to flow into this oscillatory circuit. In order not to confuse the point then under consideration, however, we merely stated this as a fact without explaining at all what occurred in the circuit.

1327. With one exception, the methods of energising

oscillatory circuits which we have discussed in the earlier paragraphs of this book, have all been based on the principle of charging up a condenser and allowing it to discharge through the oscillatory circuit.

1328. There is another method, however, which lends itself far more readily to the characteristics of a vacuum valve, and which is made use of in the tuning buzzer (*vide* Part I., paragraph 544), namely, that of passing a current through the inductive windings of an oscillatory circuit and allowing this current to oscillate.

1329. Let us take the case of an oscillatory circuit, as shown in Fig. 295, consisting of a condenser C and an inductance L, and connect across this circuit a battery B through a switch S. In paragraphs 1047 to 1084 we analysed exactly what occurred when an E.M.F. is applied to a circuit consisting of a condenser and an inductance **in series** with the applied E.M.F.; in this case, however, the inductance and condenser are **in parallel** with the applied E.M.F., so that very different results will be obtained during the charging period, that is to say, during the time that the switch S is closed.

1330. In the first place, the effect of closing the switch S will be to charge up the condenser C. If we assume that the inductance of the leads from the battery to the condenser is negligible, then this current will only be momentary, and the condenser will be charged to an E.M.F. equal to that of the battery. In the second place, the current through the coil L will, owing to the latter's inductance, start increasing gradually, and will continue to grow (to a limited value depending upon the resistance of the circuit and the applied E.M.F.) so long as the switch is kept closed. Now so long as these conditions exist it is evident

that the condenser will remain charged to an E.M.F. equal to that of the battery, but if, after a certain length of time, the switch S be opened, as shown in Fig. 296, then owing to the momentum effect of the inductance the current will continue to flow in the same direction as before.

1331. In addition to this it will be seen that the condenser PD has no longer the support of the battery E.M.F. to maintain it, and since this PD is, for the moment, acting in the same direction as the battery E.M.F., so far as the current in the inductance is concerned, the current flowing through the inductance

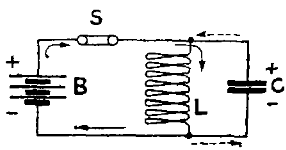


Fig. 295.

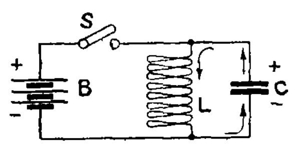


Fig. 296.

will for a short time continue to increase after the switch S has been opened until the condenser is discharged.

1332. Very soon, however, the condenser becomes discharged and immediately starts exerting a back E.M.F. against the current flowing through the inductance, which then decreases while the condenser PD increases in the opposite direction. When the current ceases to flow, the condenser PD has reached its maximum value in the opposite direction, so the current then starts flowing in the opposite direction. At this moment the conditions in the oscillatory circuit are exactly the same as those described in paragraph 1057, and the current will therefore continue to oscillate backwards and

forwards until all the energy has been expended in overcoming the resistance and other losses in the circuit.

1333. The total amount of energy stored in the circuit during the time that the battery is connected to it, will be the sum of two things—(1) the charge in the condenser, depending upon its capacity and the voltage to which it is charged by the battery, because $E = CV^2$, and (2) the charge in the coil L, depending upon the inductance of the coil and the current flowing through it, because $E = Li^2$.

1334. Evidently, therefore, the greater the E.M.F. of the battery the greater the amount of energy that will be stored in the oscillatory circuit in a given length of time, because not only will the energy put into the condenser increase in proportion to the square of E.M.F. applied to it, but also the rate of increase in the current flowing through the inductance will increase in proportion to the applied E.M.F., and, therefore, the current will reach a greater value in the limited length of time that the battery is switched on to the oscillatory circuit.

1335. This is what occurs in the valve receiver described in earlier paragraphs, and illustrated in Fig. 281. The sheath battery B, which energises the sheath oscillatory circuit, takes the place of the battery B applied to the oscillatory circuit shown in Fig. 296, and the grid G in Fig. 281 takes the place of the switch S in Fig. 296.

1336. In the case of the receiver, the grid is closed and opened, as we have shown by the action of the currents received by the aerial. **A single current impulse** in the correct direction in the aerial will therefore be

sufficient to cause a **group of damped oscillations** in the sheath oscillatory circuit, as shown in Fig. 284. But if a **group** of oscillations is received on the aerial, then the effect on the grid is to cause it to open and shut a number of times in rapid succession, corresponding to the frequency of the received oscillations, that is, every time the received oscillations reduce the negative charge on the grid.

1337. If, then, the frequency of the oscillations in the sheath oscillatory circuit (which can be controlled by varying the inductance or capacity of that circuit) is exactly the same as the frequency of the received oscillations, the grid will automatically switch on the sheath battery at the right moment to assist or reinforce these oscillations, so that while a single impulse in the grid circuit will produce a highly damped oscillating current in the sheath oscillatory circuit, similar to that shown in Fig. 284, an oscillatory current in the grid circuit will produce a very much longer group of oscillations in the sheath oscillatory circuit, as shown in Fig. 285, provided the latter is in tune with the aerial oscillations.

1338. It is evident also that if the oscillations in the grid circuit be continuously maintained, the grid will continue to switch the sheath battery on and off at the right moments to reinforce the current in the sheath oscillatory circuit, thus maintaining continuous or undamped oscillations in that circuit.

1339. In paragraphs 1293 to 1303 we showed how, by causing the oscillations produced in the sheath oscillatory circuit to react on the grid, or aerial, circuit, the damped oscillations produced in the latter by a received signal could be maintained to any desired

extent by merely increasing or decreasing the coupling between the reaction coil and the grid, or aerial, inductance coils. We also showed that if the coupling be increased sufficiently, the oscillations would be maintained for ever, or in other words, continuous undamped oscillations as shown in Fig. 286 would be generated both in the grid oscillatory circuit and in the sheath oscillatory circuit by the action of the valve.

1340. Now when the coupling of the reaction coil is adjusted so as to create these conditions, it is evident that the first impulse given to the grid circuit will start the whole system oscillating quite independently of any further external assistance from the aerial (*vide* paragraph 1336).

Thus it will be seen that the problem of producing high-frequency undamped oscillations for the purpose of detecting continuous wave-signals by the interference, or beat, method described in preceding paragraphs is solved, and it only remains to be seen how this generator can be applied most conveniently to produce the required result.

1341. Let us first of all consider the valve as a continuous oscillation generator in its most elementary form as shown in Fig. 297.

1342. On the grid side of the valve we have an oscillatory circuit consisting of a condenser C_g and an inductance L_g, while on the sheath side we have another oscillatory circuit consisting of a condenser C_s and the inductances L_s, and R, the latter being the reaction coil inductively coupled to the grid oscillatory circuit.

1343. The source of energy for the whole system is the battery B which first of all energises the oscillatory

circuit $C_s L_s R$, in the manner described in paragraphs 1329 to 1334, and secondly, energises the oscillatory circuit C_g L_g by magnetic induction through the reaction coil R.

1344. **The potentiometer battery P does not supply any energy to the oscillatory circuits,** and its function is merely to raise the initial potential of the grid to a suitable value. The energy in the grid oscillatory circuit can be very small as it only has to vary the potential of the grid over a big enough range to allow sufficient current to pass from the battery B to maintain the

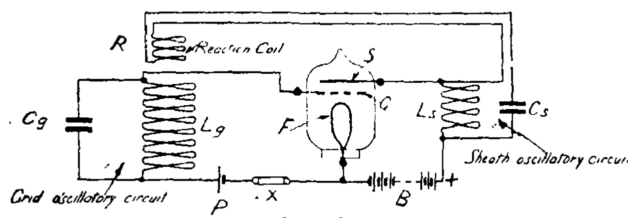


FIG. 297.

oscillations in the sheath oscillatory circuit. On the other hand, it is desirable that the energy in the sheath oscillatory circuit is the maximum possible, as it is available for operating the telephones as described in previous paragraphs, or for energising an aerial, as we shall show later. Moreover, part of its energy is used for maintaining the oscillations in the grid circuit.

1345. If the two circuits are in tune with one another, and if the reaction coil R is coupled closely enough to the grid oscillatory circuit, then, as we have already shown, the smallest variation in the grid potential will be sufficient to start the whole system oscillating. If the switch X be opened, then the grid

will become negatively charged, as described in paragraph 1267, to what we may call its natural value, *i.e.* to a sufficiently low value. depending upon the construction of the valve, to prevent any current flowing through the sheath circuit. But if the switch X be suddenly closed, then the rise in current in the sheath circuit, due to the variation of the grid potential from its natural value to that to which the potentiometer battery is adjusted, will be sufficient to start the whole system oscillating.

1346. To avoid any confusion let us examine and note the nature of the currents flowing in different parts of the valve circuit.

Taking first the grid oscillatory circuit we have feeble oscillatory currents flowing through the inductance L_g and the condenser C_g. These oscillations charge up the condenser C_g, thereby creating a difference in potential between the grid G and the filament F, which varies continually from a maximum at one moment to a minimum at the next moment. Now **the mean potential on the grid is determined by the value of the potential applied by the potentiometer.** But the maximum and minimum values of this potential or, in other words, the amplitude of the variation of the grid potential is determined by the amount of energy supplied to it by the sheath circuit, that is to say, it is determined by the coupling between R and L_g.

1347. Thus if this coupling for a particular apparatus is set so that the potential of the condenser C_g varies from a positive to a negative maximum of, say, two volts on either side of zero potential, then the potential of the grid will vary by two volts on either side of the initial potential supplied by the potentiometer. In Fig. 298,

we have illustrated by a curve diagram the variation in the grid potential, assuming that the amplitude of the variation is two volts and the initial potential supplied by the potentiometer is -7 volts.

1348. Taking next the sheath oscillatory circuit, we have comparatively powerful oscillating currents flowing through the inductances L_s and R and the condenser C_s. This current is maintained, as we have already explained, by the current which is allowed to flow into

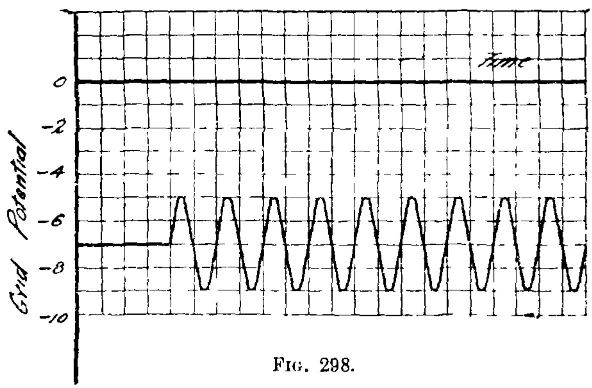


FIG. 298.

the circuit from the battery B by the action of the grid. For a very short length of time during each oscillation the grid by virtue of its raised potential allows a certain amount of current to flow into the condenser, and, through the inductance of the sheath oscillatory circuit always in the same direction, thus maintaining these oscillations at a certain maximum amplitude. **This maximum value of the current in the oscillatory circuit may be many times greater than the value of the current supplied by the battery.** It depends upon a balance of two things—(1) the amount of energy supplied to the circuit from the

sheath battery during each oscillation, and (2), the amount of energy dissipated in the oscillatory circuit during each half cycle. The less the amount of energy dissipated the greater will be the maximum value of the oscillatory current for a given amount of energy supplied.

1349 The amount of current which can be fed into the circuit is ultimately limited, for any particular valve, owing to the fact, explained in paragraph 1260, that only a definite number of electrons are available. It is also limited, however, for reasons explained in paragraph 1334, by the E.M.F. of the sheath battery B. For all practical purposes it can be taken that the magnitude of the current in the sheath oscillatory circuit of any particular valve is proportional to the E.M.F. of the sheath battery. That is to say, if the E.M.F. of this battery be doubled the amount of current flowing in the sheath oscillatory circuit will also be doubled.

1350. There are two purposes for which the oscillating valve can be usefully employed, namely—(1) the reception of undamped oscillations by the "interference" or "beat" method, and (2) the transmission of undamped oscillations or continuous waves.

Application of Oscillating Valve for Reception of Continuous Waves

1351. If the action of the oscillating valve as described in the foregoing paragraphs is clearly understood, the student will have no difficulty in following the method of applying its properties for the reception of continuous wave-signals.

1352. Suppose we replace the condenser C_g in the grid

oscillatory circuit of the general system illustrated in Fig. 297 by an aerial and "earth" as shown in Fig. 299, then, as already explained, if the circuits be properly adjusted and the sheath oscillatory circuit be in tune with the grid oscillatory circuit (which is now the aerial circuit), feeble but continuous oscillations will be generated in the aerial, and comparatively powerful undamped oscillations will be generated in the sheath oscillatory circuit.

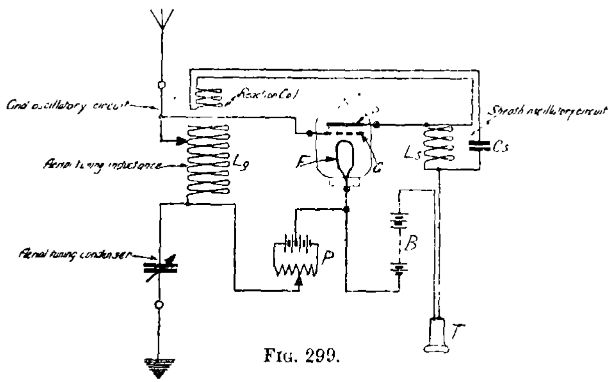


FIG. 299.

1353. If the initial voltage of the grid be adjusted by means of the potentiometer to the point −7 volts on the characteristic curve illustrated in Fig. 300, and the coupling of the reaction coil be adjusted so that the amplitude of the grid potential is, say, 2 volts, as shown by the sine curve below Fig. 300, then although the current in the sheath oscillatory circuit will be an oscillating one, that supplied by the battery, *i.e.*, the current at the point T, Fig. 299, will be a uni-directional current varying at a high frequency from 1·5 micro-amperes to 10 micro-amperes, as can be seen by taking the readings

of the curve. Thus, if we connect a pair of telephones between the battery and the sheath oscillatory circuit, the diaphragm of the telephones will then be permanently

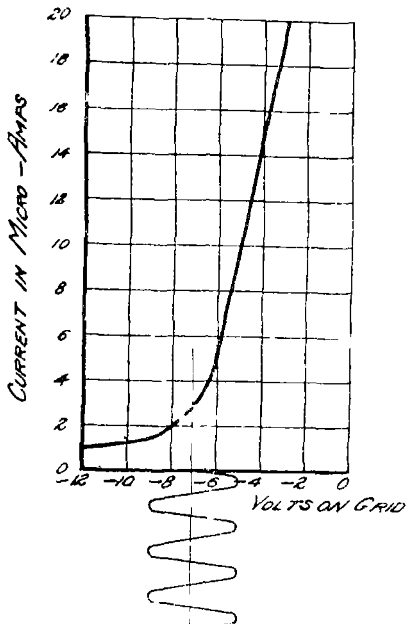


FIG. 300.

deflected to a degree corresponding to the average current, *i.e.* corresponding to $\frac{1 \cdot 5+10}{2}=6$ micro-amperes (about), and except for the first click no sound will be produced in them.

1354. If now a series of continuous oscillations be received by the aerial whose amplitude is, say, ·25 volt,

then, provided their frequency is slightly different from that of the oscillations generated in the aerial by the valve, they will have the effect of varying the amplitude of these oscillations from a maximum of 2·25 volts to a

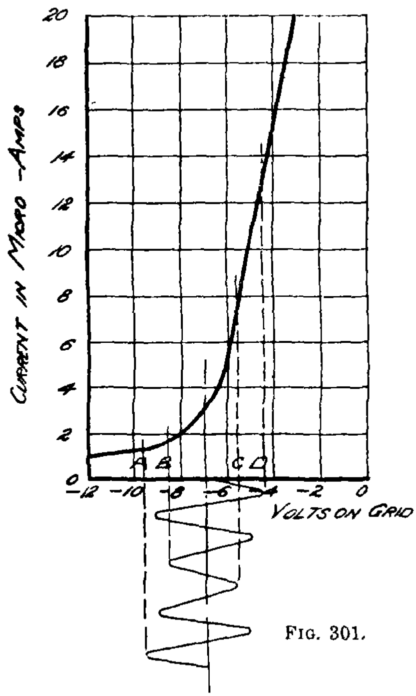


FIG. 301.

minimum of 1·75 volts, as described in paragraphs 1308 to 1325, and illustrated in the beat curve below Fig. 301. The result will be to vary the average value of the current passing through the telephones from a maximum of $\frac{3+13}{2}=8$ to a minimum of $\frac{3+7}{2}=5$,

thus producing a sound, or musical note, in the telephones, corresponding in strength to the difference between 8 and 5.

The frequency of these variations, which determines the pitch of the received note, can be adjusted to any desired value by varying the wave-length of the oscillations generated by the valve (*vide* paragraph 1320). For this purpose, therefore, the condenser C_s in the sheath circuit is made adjustable, while the aerial, or grid circuit, can be tuned by either the variable condenser or the variable inductance included.

1355. It will be seen that to receive continuous wave signals from a distant station on this type of receiver, it is necessary to tune the sheath oscillatory circuit to nearly the same wave-length as the aerial circuit, otherwise the whole system will stop oscillating. The aerial circuit, however, must be tuned to a slightly different wave-length from that of the incoming signals in order to produce the beats.

1356. For the purposes of reception the sensitiveness of the system depends not upon obtaining the greatest current in the telephones, but **upon obtaining, by the action of the received oscillations, the greatest change in the current flowing through the telephones.** Obviously, it is not desirable to generate the biggest possible continuous oscillations either in the aerial or in the sheath circuit, but merely to get oscillations of such a value that the smallest change in the amplitude of these oscillations effected by the received signals causes the biggest possible change in the current flowing through the sheath circuit, and therefore through the telephones.

1357. It will be seen that this object is achieved when

the maximum and minimum amplitude of the resultant oscillations produced by the incoming signals, or in other words **when the amplitude of the beats falls on the steepest part of the current curve on the positive side of the oscillations, and on the flattest part of the curve on the negative side of the oscillations.** This point will be more easily understood by referring again to Fig. 301. The amplitude of the beats on the positive side of the oscillations is shown by the distance CD and that on the negative side by the distance AB. Obviously the strength of the note produced in the telephones will be determined by the difference between the change in the current from A to B, and the change in the current from C to D. Thus, **the smaller the change from A to B the stronger the signals,** and **the greater the change from C to D the stronger the signals.**

Application of the Oscillating Valve for Transmission of Continuous Waves

1358. For the purpose of transmitting continuous waves obviously it is desirable to produce oscillations of the maximum possible amplitude in the aerial. We have already shown that the oscillations in the grid oscillatory circuit are very feeble compared with those which can be produced in the sheath oscillatory circuit.

1359. Suppose, then, we replace the condenser C_s in the sheath oscillatory circuit of the general system, illustrated in Fig. 297 by an aerial and "earth," as shown in Fig. 302, then if once more the circuits be properly adjusted the whole system will oscillate, but this time the more powerful oscillations will be generated in the aerial circuit.

1360. In order to control the duration of the undamped oscillations for the purpose of signalling by the Morse Code, a manipulating key K is inserted in the grid circuit. Whenever this key is opened, the grid automatically becomes negatively charged, and shuts off all current in the sheath circuit (*vide* paragraph 1267), thus preventing the latter from energising the aerial. As soon as the key is closed, however, the sudden change

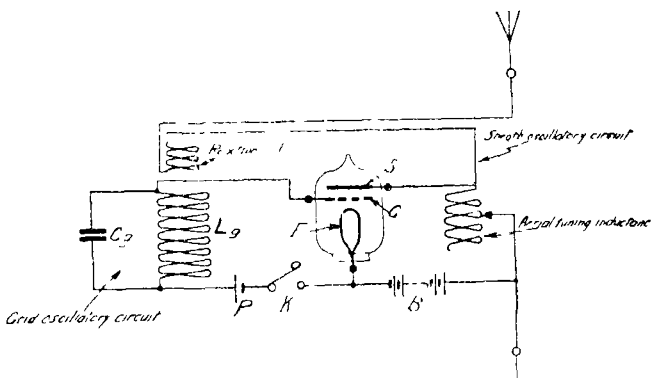


FIG. 302.

in the potential of the grid, due to the battery P, starts the whole system oscillating.

1361. In this case the exact value of the initial potential given to the grid is of no importance, so that it is quite sufficient to replace the adjustable potentiometer used in the receiver circuits by a small battery, called the Trigger Battery, to give the system a start off.

1362. To obtain the maximum current oscillations in the aerial, the coupling of the reaction coil should be carefully adjusted to that value which gives the maximum

aerial current. If this coupling be too small, the voltage swings produced on the grid will be insufficient to open the sheath circuit wide enough to allow a big enough current to flow into the aerial. On the other hand, if this coupling be too great, the oscillations produced in the grid oscillatory circuit will be far greater than is necessary to open the sheath circuit to its maximum value, so that not only will energy be wasted in maintaining unnecessarily big oscillations in the grid circuit, but also the sheath circuit will be kept open for too long during each oscillation in the aerial, with the result that for a certain length of time the battery B will be actually opposing instead of assisting the current oscillations in the aerial.

1363. Provided this coupling be adjusted to the best value, the current in the aerial circuit will be increased in proportion to the E.M.F. of this battery (*vide* paragraph 1334). With suitably designed valves a battery or dynamo having an E.M.F. up to 2000 volts can be usefully employed to energise the sheath oscillatory circuit of a transmitting valve.

1364. In the foregoing explanations, for the sake of clearness, we have assumed that **both** the grid circuit and the sheath circuit should be oscillatory circuits **in tune with one another.** In actual practice it is found that sufficiently good results, and very much simpler adjustments, can be obtained if one of these circuits is "aperiodic," that is to say, untuned. Thus in Fig. 297 either the condenser C_g or alternatively the condenser C_s may be omitted, provided that the reaction coupling is suitably adjusted.

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